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Technology Insertion (TI)/Industrial Process Improvement (IPI) Summary Report for SA-ALC/MAE/MAT. This document contains Focus Study and Quick Fix Recommendations for several Resource Control Centers (RCC's). These RCC's are: The entire flow process for the Repair of Gas Turbin Engines.
Also includes Simulation Modeling Info for these RCC's.

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COORDINATION

AFLC/ENI	Pat McWilliams	24 Jul 91
AFLC/PA	MSgt Cornell	25 Jul 91

TASK ORDER NO. 15
MDMSC RESPONSE TO HQ AFLC COMMENTS

1. A. Concur - Correction included in REV A CSR.

   B. Concur - Correction included in REV A CSR.

   C. Concur - Correction included in REV A CSR.

   D. The Designation of the arrays is correct as reflected in the CSR. The L_9 array contains factors over which GTE engineering and production personnel had little control (Noise). Manpower reductions could be directed at any time by ALC management; workload was affected by military requirements and budgets, reject rates were not statistically controlled under the current process, and floating stock/WIP levels were a product of past production/induction rates. The factors in the L_4 array, however, were considered to be controllable (or potentially controllable) by the GTE community. The actual experimental results would be unchanged, regardless of the designation of an array as "inner" or "outer" as the relationship between the arrays was fully factorial (all possible combinations of all experiments were modelled). The designation of "inner" and "outer" arrays in the DDB is incorrect, however, and has been corrected in REV A.

   E. Concur - Correction included in REV A CSR.

2. No. MDMSC did not propose further MDMSC engineering services because they felt that this work was well within the technical (and engineering manpower) capabilities of SA-ALC engineers, and did not require additional assistance. If SA-ALC engineers disagree, MDMSC will be happy to provide a proposal for any desired assistance.

A-1

TASK ORDER NO. 15
MDMSC RESPONSE TO SA-ALC COMMENTS

These responses are numbered to correspond with the order in which the comments appear.

1. Please see correction requested in comment 1.E. of A/Q AFLC comments.

2. Correction included in REV A CSR.

3. The FPI specialist mentioned is Mr. Roger Engelbart, who is one of the most knowledgeable experts in this field in MDMSC. His resume is attached. MDMSC didn't "settle" for Mr. Engelbart. We just had difficulty finding him and scheduling his visit.

4. Concur - Correction included in REV A CSR.

5. Concur - This opinion is quite likely correct.

6. Switching engine clocks in the field would not change the average field hours reported by MDMSC. It would however, cause the distribution to shrink (when low-time clocks were swapped with high-time clocks). Given the extremely large sample collected by MDMSC reflecting data logged between 1986-1990 from all over the world, this practice would have to be extremely widespread to affect the distributions significantly.

7. MDMSC didn't mean to indicate that these workers were too skilled for their jobs - only that they had skills that would qualify them for other jobs as well. This comment has been eliminated in the REV A CSR.

8. The actual volume of parts routed to Bldg. 360 for cleaning <u>is</u> small and is included in the modeled data. Given this low volume (and the quality problems experienced with Bldg. 360 cleaning) the current GTE cleaning process is a bottleneck. The new cleaning line will be a significant improvement. MDMSC engineers were informed that the blast booths could not be sealed because of funding problems. Sealing these booths will eliminate a minor but irritating process problem. Excellent idea.

9. Concur - Correction included in REV A CSR.

10. This Data is shown in Figure 8.1-5 of the CSR.

11. Concur - Engines which cannot be repaired in the test cell are rejected and returned to final assembly. The flow time shown across the test cells reflects this.

12. Concur - MDMSC also examined the statistical data which supported the conclusion.

13. The two-bearing -180, though an old design, is newer than the -397 and still in production for a small customer base. The 4-bearing -397 is no longer manufactured at all (according to the Garrett Representative). The other engines mentioned were not included in this Task Order.

14. Both are right. The APIS stations are technologically advanced and produce adequate quality, however they are too slow (or there are not enough of them) to keep up with other areas in the process.

15. The 10% is simply the MDMSC FPI specialist's best professional estimate, based on his familiarity with the process(es) used. Should SA-ALC engineers have further questions, Mr. Engelbart can be reached at (314) 234-0919.

16. MDMSC originally proposed the use of interview data for Back shop processing times. SA-ALC engineers instructed MDMSC not to conduct interviews in these areas, but rather, agreed to use standard data for model validation. The reasoning behind this was that, given the enormous ratio of flow time (based on WCD history) and process time, the UDOS model was insensitive to even very large changes in process times. Adequate log book data was not available at the time the model was validated, although small amounts did become available by the end of the contract period of performance. (Production personnel in the back shops were far less cooperative/successful in filling out process logs than the schedulers were in filling out tracking tags). This log book data was given to SA-ALC engineers (the log books and tags themselves were also left in place) prior to the end of the contract period of performance. MDMSC also provided considerable UDOS 2.0 training to SA-ALC engineers (at no cost to the Air Force), thus giving them the capability to test the effects of any log book data that has been collected by MDMSC or SA-ALC personnel.

17. Correction included in REV A CSR.

18. Feedback noted. Thank you.

19. The data on engine/subassembly WIP levels was provided by the appropriate MM item managers. The MM point of contact was Ms. Ruth Agueros and her data is included in the DDB on pages 693-696, Section 8.3.1.1. MDMSC engineers were aware that a WIP inventory audit had been previously performed on the GTE workload, but were never allowed to see the results in spite of repeated requests. The MM data was used as the best available. As described in the MDMSC Task Order No. 15 proposal, MDMSC is not responsible for using/evaluating any Government Furnished Information not provided by the government.

The MDMSC estimate of 11,000 sq.ft. as parts pool floor space was produced/described in the GTE process characterization performed under Task

Order No. 1. MDMSC's suspicion that large quantities of WIP are stored in the parts pool is based on the actual observation of shelves/bins filled with parts and MDMSC's understanding that the parts pool's mission is the accumulation/storage of WIP prior to assembly.

20. The practice of inducting GTE's to be cannibalized for parts to repair other GTEs causes two problems:

    1) WIP inventories grow and the repair process becomes clogged with parts.

    2) The actual replacement part requirements cannot be determined as parts are not ordered, only robbed from other engines.

    MDMSC's recommendations regarding this situation are described in the last paragraph on page 8.3-6 of the CSR.

    The cost estimating rationales for the $93,299 and the $3,542 are described on pages 8.2-1 and 8.3-1 of the Quick Fix Plan (QFP) respectively.

21. MDMSC engineers did not doubt that relaxing the cement has helped, but did question the statement that the problem was "solved", given the very small amount of data collected after the change and the very large variation in the data collected before the change. If the improved trend continues, SA-ALC engineers can safely conclude that they have solved a difficult process problem and MDMSC engineers will be the first to offer congratulations. MDMSC concurs that process problems should be solved systematically and has offered several detail suggestion on how this could be approached. We tried to help, not just criticize.

22. The information on the cement was provided to MDMSC by Mr. Lenny Bay, an SA-ALC engineer in the GTE community.

    Pre-Balance - MDMSC engineers recommend this be considered. We hope the SA-ALC engineers studying the problems will concur.

23. Concur.

24. MDMSC's analysis indicates that these parts can be processed, on the average, in the times shown on Table 8.1-1 of the QFP. This processing includes the process steps shown on figures 8.1-1 through 8.1-3 (including FPI inspection). Cleaning is not included in these processes. These figures are UDOS 2.0 estimates. The output sheet showing this is page 804, section 8.1 QFP, of the DDB.

ROGER W. ENGELBART

Position:

Staff Specialist - Quality Assurance
Missile Airframe Technology
MDMSC

Education:

1989; M.S., Mechanical Engineering (Materials Science); Washington Univerisity - St. Louis

1983; B.S., Metallurgical Engineering; University of Missouri - Rolla

Experience:

Mr. Engelbart has over 17 years of experience in the field of nondestructive testing, in both production and R&D applications. He is currently assigned to the MDMSC Missile Airframe Technology Center of Excellence, with responsibility for IRAD investigations and CRAD programs focusing on the use of advanced materials in missile airframes. He is certified as as Level III in radiography, magnetic particle, and liquid penetrant by MDMSC and by the American Society for Nondestructive Testing (ASNT). Mr. Engelbart has eight publications and was elected a Fellow of ASNT in 1989.

Enclosure (5)
22 Feb 1991
NKX-LAM-ESG7-3444

Task Order No. 15 Contract Summary Report Revision Instructions

1. Remove Title Page and insert Title Page Rev. A.
2. Remove page iii and insert page iii Rev. A.
3. Remove page v and insert page v Rev. A.
4. Add page vii Rev. A.
5. Remove page E-1 and E-2 and insert page E-1 and E-2 Rev. A.
6. Remove page 8.0-2 and insert page 8.0-2 Rev. A.
7. Remove page 8.1-2 and insert page 8.1-2 Rev. A.
8. Remove page 8.1-9 and insert page 8.1-9 Rev. A.
9. Remove page 8.1-11 and insert page 8.1-11 Rev. A.
10. Remove page 8.1-16 and insert page 8.1-16 Rev. A.
11. Remove page 8.1-17 and insert page 8.1-17 Rev. A.
12. Remove page 8.2-2 and insert page 8.2-2 Rev. A.
13. Remove page 8.3-4 and insert page 8.3-4 Rev. A.

INDUSTRIAL PROCESS IMPROVEMENT-ENGINEERING SERVICES PROCESS CHARACTERIZATION TASK ORDER NO. 15

VOLUME V
SA-ALC

CONTRACT SUMMARY REPORT/QUICK FIX PLAN
14 DECEMBER 1990
REVISION A
22 FEBRUARY 1991

CONTRACT NO. F33600-88-D-0567
CDRL SEQUENCE NO. 15A008 AND 15A010

MCDONNELL DOUGLAS
McDonnell Douglas Missile Systems Company
St. Louis, Missouri 63166-0516 (314) 232-0232

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EXECUTIVE SUMMARY

The McDonnell Douglas Missile Systems Company's (MDMSC's) work under Task Order No. 15 was conducted at SA-ALC from 16 July 1990 through 14 December 1990. As called for in the SOW, a Universal Depot Overhaul Simulator (UDOS) 2.0 model of the repair process for the -180 and -397 Gas Turbine Engines (GTEs) was constructed and a detailed engineering assessment of the repair process was conducted. As a result, MDMSC was able to recommend three process improvements as Quick Fixes (QFs) (requiring little or no capital investment) with a savings potential of $2,242,130. MDMSC also recommended two focus studies with potential annual savings realized by establishing a Just In Time (JIT) flow in the GTE repair process and developing a Statistical Process Control (SPC) program to reduce rework. These focus studies will require additional SA-ALC manhour expenditures to complete. Three additional observations were made as process improvement recommendations but which could not be adequately quantified for presentation as QF/FSs.

The simulation model was completed on schedule and was used to quantify the results of MDMSC's recommendations. MDMSC has provided over-the-shoulder and formal classroom training to interested members of the SA-ALC engineering community in the use and development of the UDOS 2.0 model. This training was not a contractual requirement but was considered important to long term program success.

MDMSC's assessment of the GTE repair process revealed that 96% of a GTEs flow time is spent in non-productive delays. No resource constraints were discovered to account for this and the problem appears to be one of scheduling rather than capacity. The bulk of this "mystery" delay time is spent in various back shops in the MAT (now LDT and TIM) and MAE (now LPP) divisions at SA-ALC. MDMSC's recommended solutions to this problem included the design of a machine cell in the GTE area and the establishment of a JIT flow.

The GTE community is currently experiencing high failure/rework rates (24% for FY90) at the final test operation, as well as lower than expected field lives. This problem is attributable to both the GTE repair process itself and to the obsolete and extremely variation-sensitive design of the two GTEs studied. MDMSC recommends the institution of an On-Condition Maintenance Program, to replace the current labor-

intensive overhaul process and the use of SPC to identify and track critical tolerances and the processes which maintain them.

MDMSC did not specifically address wartime surge requirements, as these were analyzed in some detail under Task Order No. 1. No significant process changes or capital investments (with the exception of the new cleaning line, which is still under construction, and the transfer of machining work in-house to Bldg. 329, which shortens flow time but does not increase overall capacity) have been made in the GTE repair process since Task Order No. 1.

8.0 INTRODUCTION

This report summarizes MDMSC's process characterization of the repair process of the -180 and -397 Gas Turbine Engine (GTEs) as it is performed at the San Antonio Air Logistics Center (SA-ALC), Kelly AFB, Texas. This process characterization was performed in accordance with the applicable general Statement of Work (SOW), the Task Order No. 15 SOW, and the MDMSC Task Order No. 15 proposal.

Process performance data was collected by MDMSC engineers and input to the UDOS 2.0 depot simulation model developed under Task Order No. 1 of the Air Force Industrial Process Improvement Program. This simulation model was validated in accordance with the applicable Acceptance Test Procedure. The model was used to analyze the current As-Is GTE repair baseline at SA-ALC and evaluated the impact of proposed changes. This analysis included the identification of critical resource constraints and areas of potential improvement.

In addition to the simulation work, MDMSC performed an engineering assessment of the current operations and resources within the GTE repair process. The MDMSC on-site engineering staff was supported in this effort by the following specialists:

- One Fluorescent Penetrant Inspection Specialist
- One commercial aircraft maintenance expert from Embry-Riddle Aeronautical University (ERAU)
- One Chemical Engineer

The on-site technical team consisted of three industrial engineers, one mechanical engineer, and one computer simulation specialist.

Two of the primary Resource Control Centers (RCCs) in the GTE repair process (MATPGB and MATPSI) were modeled previously under Task Order No. 1. Wherever possible, the validated data collected during Task Order No. 1 was used in the performance of this task order (after SA-ALC engineering review). This task order differed significantly from any performed under Task Order No. 1, however. Rather than study the operation of a single RCC, this task order studied the entire flow of two end items (the GTEs) through all of the RCCs that perform repair work on those items.

This approach (selected by SA-ALC engineers) offered a number of advantages over the traditional method:

- It made the identification of the end-item critical path possible.
- It prevented the development of "sub-optimal" recommendations, which improved the performance of some RCCs but did not improve the overall performance of the depot itself.
- It allowed the identification of "mystery" delays in end-item flow, where items waited for no apparent reason.

MDMSC recommends that this approach be used in future task orders wherever feasible.

Because the structure of this task order differed from the standard model, the format of this report has been modified accordingly. Rather than describe the technology, resources, and processes found in an entire RCC, this report describes those factors for each of the primary RCCs involved in the repair of the selected GTEs. The paragraph on "Specific Process Concerns" describes those concerns which MDMSC judges as significant to the repair of GTEs at SA-ALC.

During the performance of this task order, SA-ALC was reorganized, with new office symbols assigned to many areas. Because the old office symbols are called out in the Task Order No. 15 SOW and proposal, MDMSC has elected to continue their use. The division previously known as MAT is now designated LDT.

8.1 GTE OVERHAUL PROCESS

In accordance with the Task Order No. 15 SOW, MDMSC has analyzed and modeled the complete flow of two GTEs through the entire overhaul process. This paragraph documents MDMSC's findings and describes the results of the simulation model.

The GTE's flow was tracked through nine different RCCs, including two dedicated to GTE work (MATPGB and MATPSI) and seven back shops. While each GTE is disassembled into roughly 65 subassemblies, MDMSC concentrated on 17 subassemblies which were selected by SA-ALC personnel as critical. Table 8.1-1 shows the breakout of these critical parts by GTE.

The current repair process used for GTEs is 100% overhaul. Each GTE is disassembled to its component parts, which are then cleaned, inspected, repaired (or replaced), and reassembled into a new GTE. This new GTE is then tested and (if it passes) shipped to the field. Figure 8.1-1 shows the generic process flow for a GTE.

It is misleading to talk about the flow of one GTE, as individual GTEs lose their identity following the disassembly step and never actually regain it. The scheduling system produces the appearance of individual engine flows by removing the *serial number* plate at disassembly and affixing it to a "new" GTE (one which may have absolutely no parts in common with the original) during assembly. This practice is absolutely unheard of in commercial aviation (Civilian Federal Aviation Regulations forbid it) and is extremely questionable in the SA-ALC GTE process. MDMSC identified this practice in Task Order No. 1 and strongly recommended that it be discontinued immediately. It remains in effect and MDMSC repeats the recommendation that it be discontinued. This is discussed further in Paragraph 8.3.1.1 of this report.

Figure 8.1-2 illustrates the actual "flow" of GTEs through the overhaul pipeline. As shown there, GTEs are disassembled and allowed to enter an enormous inventory of untracked, unscheduled, and uncontrolled GTE parts. Some order is re-established when parts are kitted in the parts pool, but no one has any idea of the real condition of the parts in the parts pool, or how long they have been there. According to the final assembly log data examined by MDMSC, 184 parts from the parts pool were rejected at final assembly during a three month period (June - Sept 1990). This problem is discussed further in Paragraphs 8.1.2 and 8.3.1.2 of this report.

GTE CRITICAL PARTS BREAKDOWN
TABLE 8.1-1

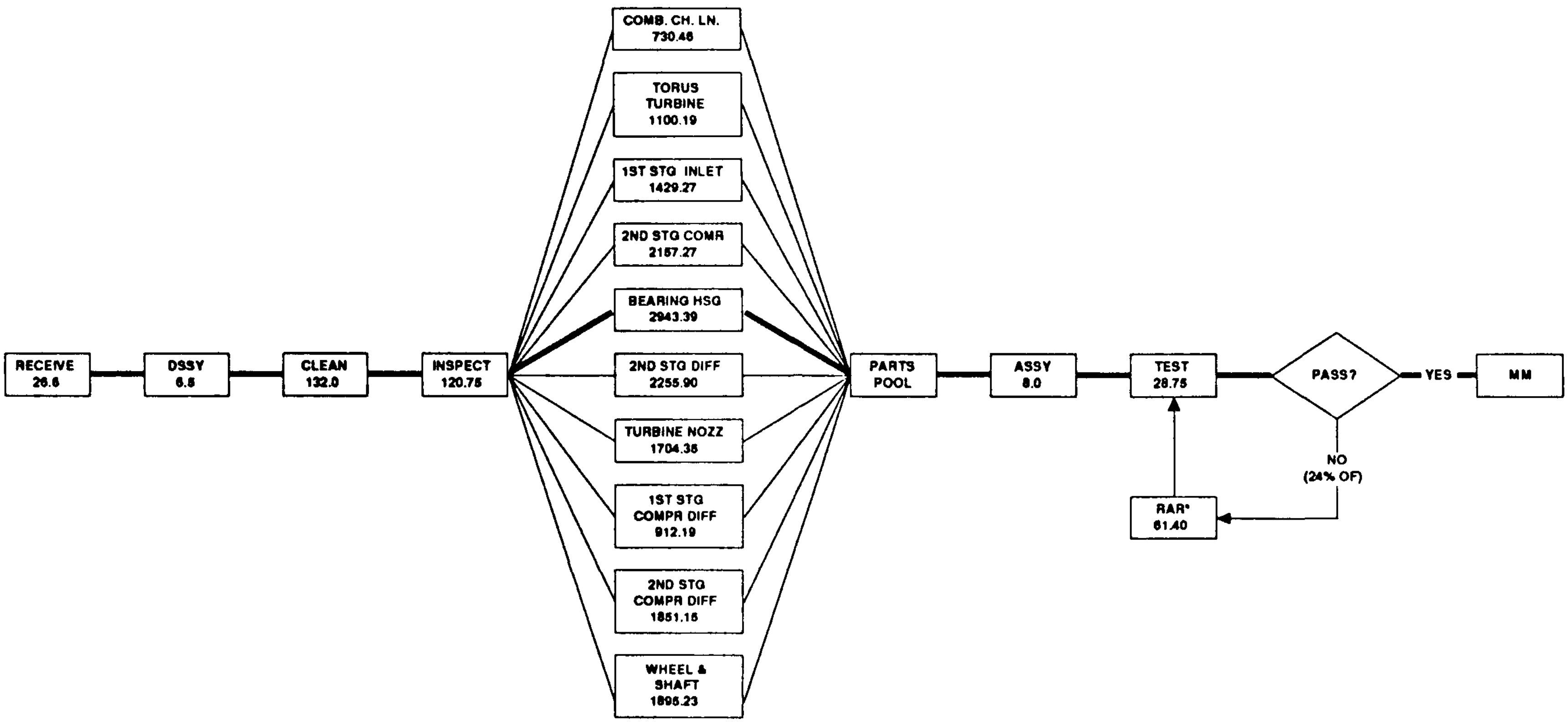
GTCP85-180

ITEM	P/N
Combustion Chamber Liner	899244-3
Turbine Torus	968959-2
1st Stage Inlet Assembly	698197-1
2nd Stage Compressor Housing	698198
Wheel and Shaft Assembly	3606982-1
2nd Stage Diffuser Housing	698195-1
Turbine Nozzle	968886-1
1st Stage Compressor Diffuser	698194-1
2nd Stage Compressor Diffuser	892290-1
Bearing Housing	696659-160

GTCP85-397

ITEM	P/N
2nd Stage Housing	372647-100
Deswirl	76443
2nd Stage Diffuser	373823
Accessory Drive Housing	372896-16
Compressor Inlet	376283-20
Turbine Nozzle	378513-4
Turbine Bearing Housing	373237-200, 250

20993

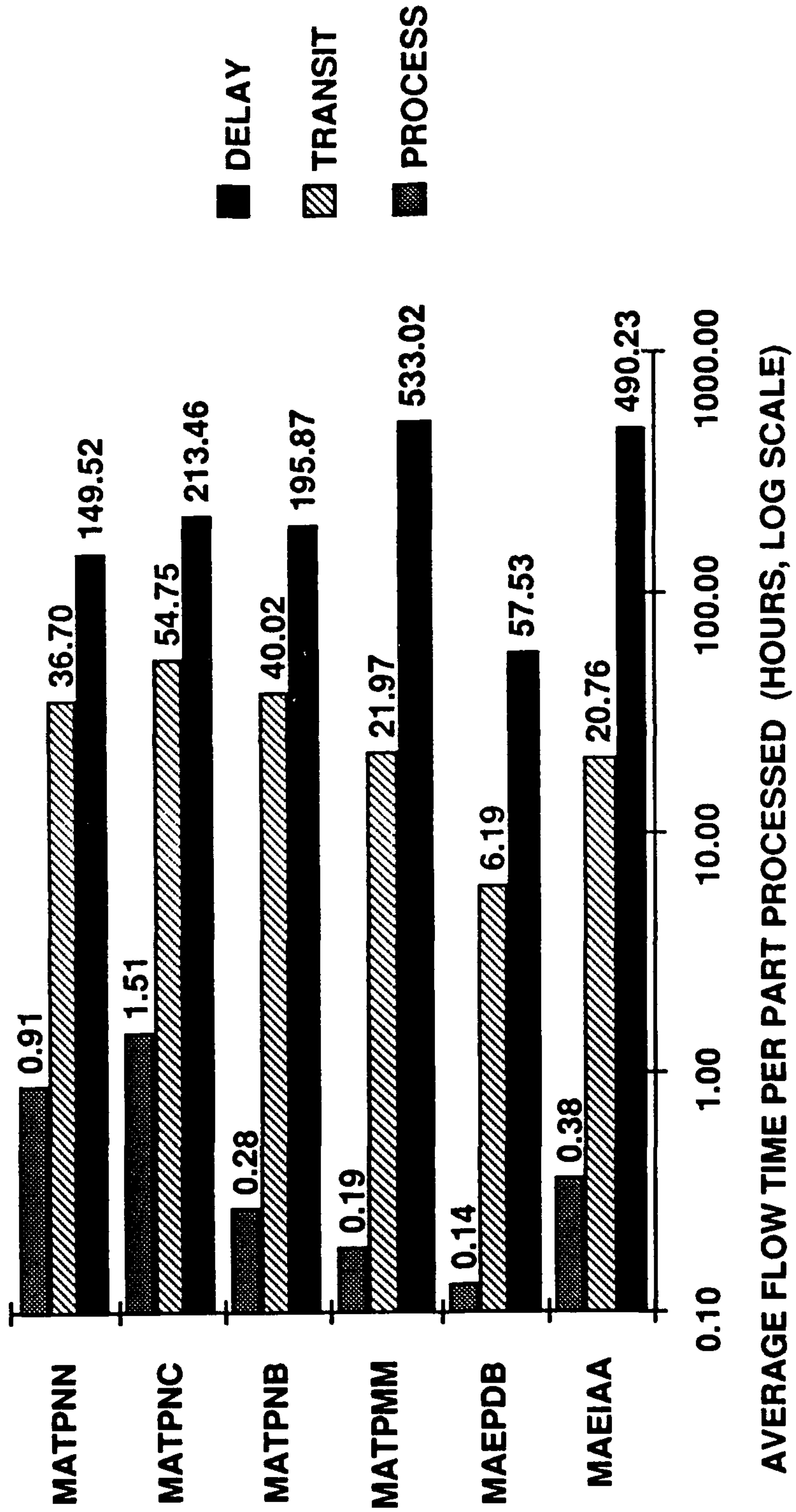


NOTE: PROCESS TIME (IN HOURS) ARE SHOWN IN EACH BOX. THE HEAVY LINE INDICATES THE CRITICAL PATH FOR THE -180 GTE. THE BEARING HOUSING IS THE PACING ITEM ON -180 PRODUCTION.

* RAR: REPAIR AS REQUIRED

20941

-180 GTE CRITICAL PATH
FIGURE 8.1-4



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AVERAGE BACK SHOP FLOW TIMES
FIGURE 8.1-5

1000 hours for the -180 and 650 hours for the -397. 100% overhaul is obviously not producing the desired quality/reliability any more than OCM did. The actual sources of quality/rework problems are discussed in Paragraph 8.1.2, while MDMSC's recommendations are detailed in Paragraph 8.3.1.2 of this report.

8.1.1 GTE Overhaul Operations Descriptions

The following paragraphs describe the details of the primary individual operations in the GTE overhaul process. They include the operations performed in MATPSI and MATPGB, as well as descriptions of the principle back shop operations.

8.1.1.1 Disassembly Operation

Engines are disassembled in the MATPGB disassembly shop located in Building 329. They are brought in from a storage area located in a different building. Each engine is mounted on a stand while a mechanic strips it into its separate components. The parts are placed together on a cart which is then removed from the disassembly area into a staging area where the parts are prepared for cleaning.

Manpower currently consists of nine workers. There are six WG 10s, one WG 9, and two WG 5s. The WG 5s are used as helpers, primarily for uncrating and routing. The remaining workers (WG 9 and WG 10s) perform the engine disassembly. At this time the disassembly area is only working one shift (day) and overtime is rare. This area is not having problems in keeping up the production rate. The labor force is more than adequately skilled and trained to perform the disassembly operation. The manpower distribution in MATPGB is such that WG 10s are used to disassemble the GTEs and WG 9s are used to assemble them. This is exactly the opposite of the situation common in similar commercial operations, and leads to MDMSC's recommendation in Paragraph 8.2. that some of these craftsmen be retrained as inspectors. The equipment in use consists of engine stands and hand tools. One engine stand is used for each engine for the disassembly process. Given the simple nature of the work involved, the equipment condition and quantity appear to be adequate for the job.

The technology used for the disassembly process is adequate. Because the process is so basic in nature, the current manual processes are unlikely to be improved through the insertion of additional technology. On average it takes a craftsman about 1 - 1 1/2 days to disassemble a GTE.

The current labor standard for the disassembly of the 180 GTE is 8.68 hours and 10.90 hours for the 397 GTE. Flow through the disassembly area is smooth. Any delays normally occur at the end of the process where parts are segregated and loaded into cleaning modules. At this point, slight delays sometimes occur until sufficient quantities of similar material parts accumulate to fill the cleaning modules. The addition of the new automated cleaning line in Building 329 will eliminate this delay by allowing immediate cleaning of most parts without the assembly of cleaning modules.

8.1.1.2 Cleaning Operation

GTE cleaning is performed in a two phase process. The first phase involves a pre-cleaning using the automated cleaning line in Building 360. Prior to sending them to Building 360 the GTE parts are segregated by material type and loaded into large cleaning modules. The modules are labeled with a tag specifying the cleaning process required. After the modules are filled they are placed in a holding area awaiting pickup and transportation to Building 360. There they are run through one of the automated cleaning lines and returned without being removed from the module. The entire round trip to Building 360 takes nine to ten days on the average. They return to Building 329 just outside of the disassembly area. The modules are broken apart and secondary cleaning is completed by MATPSI personnel in Building 329. The secondary cleaning in MATPSI is done primarily using manual processes (soaking, wire brushing, abrasive blasting).

MATPSI cleaning is now undergoing a major improvement to their cleaning process. A new semi-automatic cleaning system has been installed in Building 329, next to the disassembly area. The goal of the new cleaning line is to reduce the dependence on Building 360 by bringing the cleaning workload into Building 329 and under the control of MATPSI. With the opening of the new line, only large parts will be sent to Building 360 for cleaning. All other parts will be cleaned in-house. With the new cleaning system, parts will be individually tagged according to material type and cleaning process required. After tagging, parts will be placed in small baskets and are

inspect GTE parts. The people in the GTE inspection area are very heavily utilized. Any large increase in workload will cause a significant bottleneck in production. Surges in workload caused by DESERT SHIELD, for example, have created a backlog of parts in front of the inspection process. The FPI area is also very highly utilized and any large increase in workload would cause a build up of backlog in this area.

There are a total of 17 workstations in the GTE portion of the inspection area. All the equipment appears modern and in good condition. The FPI line consists of a penetrant dip tank, curing area, manual rinsing booths, a developer dip tank, and drying oven. Sections of the line are connected by sections of roller conveyor. Baskets are dipped using manual hoists. There are two blacklight booths for FPI interpretation and one booth for the MPI process located in the room between the FPI prep area and the inspection area.

The technology of the inspection process is adequate. The FPI methodology is the most cost effective way to inspect used parts for cracks and is in wide use throughout military and civilian industrial centers. The current FPI line requires a great deal of manual effort to operate and would benefit from the MDMSC recommended changes described in Paragraph 8.1.3. The dimensional inspection area has adequate equipment. The APIS systems are technologically advanced and are doing a good job. Flow times through the NDI portion of the inspection process are tough to estimate because it is difficult to track the GTE parts before paper work is attached. Flow data for the process does not exist at this time. The current engineered labor standard for NDI is 5.67 hours for the 397 GTE and 6.33 hours for the 180 GTE.

Flow time through the dimensional inspection area is easier to estimate because paper work is attached to each part after the NDI process. Most parts take about two to three days to dimensionally inspect. However, some parts are very time consuming to inspect and only the minimum requirements are completed. There is currently an accumulation of some "hard to inspect" parts growing in the inspection area. The reason this may be occurring is because of an inequity in the way the various RCCs are paid for their effort. Currently, payment is made for each GTE that is completed at the end of the process. MATPSI is currently being "paid" 8.54 hours to inspect 397 GTE parts and 19.91 hours for 180 GTE parts. However, because many more GTEs are inducted than are actually completed, shops near the beginning of the GTE repair

process are asked to process a significantly higher number of parts than they are being "paid" for.

Currently, most parts are routed to the back shops that are listed on the WCD paperwork, in the order they are listed. Each back shop then inspects the part and either performs the required operations or stamps the WCD operation as not required. The part is then sent on to the next back shop listed on the WCD and the process is repeated. With this routing process it is possible for a part to spend a great deal of time traveling from shop to shop for no reason which may explain some of the mystery time between long flow times and short process times in the back shops. Much of the responsibility for the rework decisions are passed on to the back shop. A considerable amount of flow time could be eliminated if the routing of a part was specified by the inspection area based upon information obtained during the inspection process. Inspection of parts at the completion of the repair process would help to prevent rejects at final test by removing bad parts before they are built into engines. Inspection at this point would also provide valuable feedback to the back shops in a more timely manner in the event of defective work.

8.1.1.4 Back Shop Operations

The bulk of the repair of GTE parts is performed in various back shops. The following sub paragraphs provide brief descriptions of the back shops contributing the most work (and flow time) to the GTE repair process. Figure 8.1-5 shows the average relationship of process, transit, and delay times in each back shop.

MATPNC - MACHINE SHOP

The machine shop located in Building 303 is responsible for machining processes related to aircraft, aircraft engines, and GTE component repair. The GTE workload in this area has its own dedicated equipment and personnel.

This area has an efficient layout. It is well lit and clean, and items are neatly organized on stainless steel racks located throughout the shop. These racks are an excellent addition to the area, and make it very easy to tell how much work in process (WIP) is present. The fact that certain racks are dedicated specifically to in-coming and out-going parts makes material handling much easier, and contributes to the fact that material transport and handling practices in the area were relatively efficient.

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The amount of WIP present is substantial. This accounts for the lengthy, historically-documented flow times in this area. This flow time does not have much to do with the actual processing of items in this area, but more with a lack of structured production goals for this area. The individual machinists produce only the number of items necessary to meet the minimal production quotas for GTE end items for each month, however, they receive a significantly larger number of individual components (due to over-inductions) than they produce in a given month. Items become buried under ever increasing WIP, which contributes to the quality problems in the GTE process. Items which are rejected at final assembly may circulate through the system continually, as no records are kept.

MATPNB - FPI

This area is located in Building 303, and performs non-destructive inspection of a variety of items, including GTE components. This back shop function proved to be one of the most efficient at processing items in a timely manner.

The same inspection capability presently exists in-house for the GTE repair process. If machining an/or other repair processes were moved in-house to Building 329, the facility there could be used to process the workload now performed in Building 303.

MATPNN - WELDING

GTE welding tasks divide into two major categories: Build-up processes, including plasma spray, and general sheetmetal repair. The build-up processes are usually closely associated with machining practices, and any movement of parts to an in-house machining process would require associated welding support.

MAEIAA - PLATING

The greatest percentage of plating operations performed on GTE components in this RCC involve anodizing processes. These require pre-cleaning, masking, and a relatively simple tank process, all batch operations which do not require the same items to be processed simultaneously. The process currently used, is a "barrel" plating operation. Other GTE plating processes include chrome plating and hard coat anodizing.

8.2 SIMULATION MODEL

A simulation model was constructed by MDMSC engineers under the supervision of an on-site simulation specialist, using the UDOS 2.0 model. This simulation modeled the entire process flow of two selected GTEs (the -180 and -397 engines) through their entire repair process, from induction through final sell. This process flow included the individual flows of 15 critical subassemblies (selected by the SA-ALC engineer assigned to Task Order No. 15) across seven separate RCCs. By following two end items across the entire process, the problems of "sub-optimalization" (increasing the efficiency of a portion of the process but not significantly affecting the whole) found in some individual RCC models were avoided. MDMSC commends the SA-ALC engineers for specifying this modeling process and recommends it become the IPI process characterization method of choice on future Task Orders.

The flow times of various parts through the repair RCCs were modeled using historical data collected from PAC-stamped WCDs. MDMSC collected and key punched the flow times shown on representative samples of WCDs completed in FY 90. Histograms were prepared from this data and used to develop average flow times and their probabalistic distributions for use in the UDOS model. This flow data was reviewed by SA-ALC engineers prior to use and is considered the most accurate flow data available. It is reported by GTE and subassembly, across each RCC and primary operation in Paragraph 8.1 of this report. The details of this data can be found in Section 8.2 of the DDB.

While historical flow time data was available between RCCs, it was not available for individual operations within RCCs nor for the actual process times (touch times) required for each operation. This data was obtained from the validated UDOS files generated under Task Order No. 1, updated as required with data collected from shop floor interviews. In back shops, at SA-ALC engineering request, MDMSC used current SA-ALC labor standards (from the GO19C report) to model process times. This data is displayed in Paragraph 8.1 of this report, and in Section 8.2 of the DDB.

The UDOS 2.0 model was validated in accordance with the Acceptance Test Procedure (ATP) called out in MDMSC's proposal. As required by the ATP, model outputs were compared to historical data collected on the GTE repair process. All simulated flow times were within 15% of the historical average and all simulated

throughput figures were within 10% of historical performance. Details of the validation procedure can be found in Section 8.2 of the DDB and the validation report submitted by MDMSC as CDRL item 15AO17. The final phase of validation was witnessed by the IPI working group member (acting) at SA-ALC.

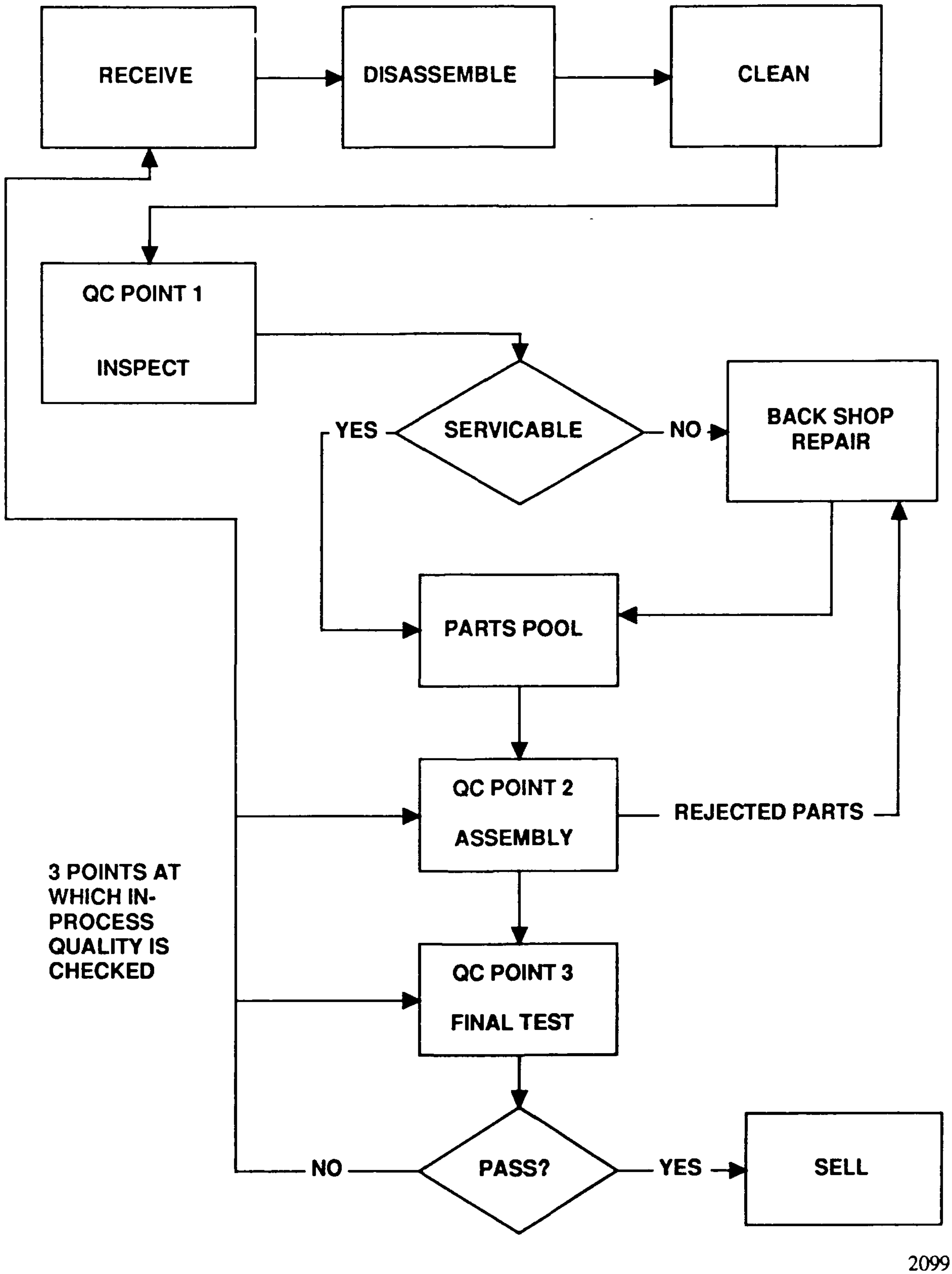
The validated model was run at three random seeds. At a 95% confidence interval the flow time variance attributable to random seed changes decreased insignificantly between two seed runs and three. This led MDMSC to decide to use two random seed runs for each model experiment. Figure 8.2-1 shows this graphically. More detail can be found in Section 8.2 of the DDB.

8.2.1 Additional Data Collection

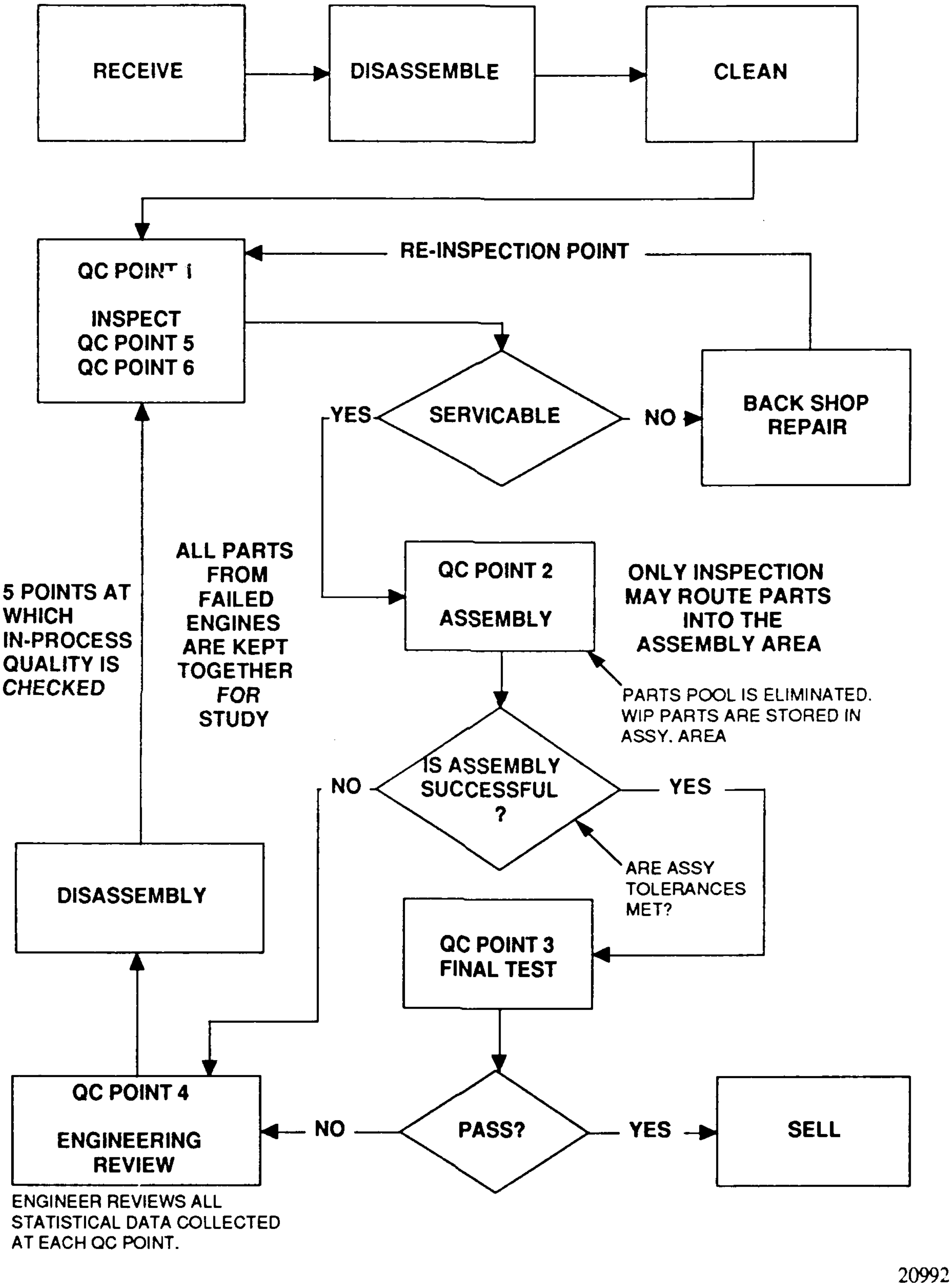
At the request of SA-ALC engineers, MDMSC began a parts tagging program to provide additional data on the flow of GTE parts through the SA-ALC repair process. While not required by the Task Order No. 15 contract, MDMSC agreed to perform this task in an attempt to increase SA-ALC satisfaction with the task order performance.

The program itself involved tagging critical parts, using blue cardboard "Traveler" tags prepared by MDMSC. Figure 8.2.1-1 shows one of these tags. The tags were placed on critical subassemblies of the -180 and -397 GTEs, at various points in the repair process. Material handling workers in both MAT and MAE were briefed on the program and requested to log the dates and times parts were moved between RCCs/operations. This data was collected to evaluate GTE flow times. Production supervisors in each RCC affected were provided with logbooks and asked to log the production time spent repairing each tagged item. This data was collected to evaluate GTE processing times.

This program was operated for roughly three months by MDMSC engineers (devoting an estimated 400 manhours to the effort). During this time 800 parts were tagged and 283 tags were collected at the designated collection points. Given the relatively short duration of the study and the long flow times for GTEs (four to five months), the program failed to yield a detailed picture of the flow of GTEs. It did, however, yield data on certain points in the process (showing for example, that the actual average flow time for a basket of GTE parts through the Building 360 cleaning line is currently



CURRENT GTE PROCESS FLOW
FIGURE 8.3.1.1-1



RECOMMENDED GTE PROCESS FLOW
FIGURE 8.3.1.1-2

Enclosure (8)
22 Feb 1991
NKX-LAM-ESG7-3444

Task Order No. 15 Database Documentation Book Revision Instructions

1. Remove Title Page and insert Title Page Rev. A.

2. Add page i Rev. A.

3. Remove page 572 and insert page 572 Rev. A.

INDUSTRIAL PROCESS IMPROVEMENT-
ENGINEERING SERVICES
PROCESS CHARACTERIZATION
TASK ORDER NO. 15

DATABASE DOCUMENTATION BOOK

SA-ALC

MAE & MAT

(ENTIRE REPAIR FLOW OF SELECTED GAS TURBINE ENGINES)

CONTRACT SUMMARY REPORT
14 DECEMBER 1990
REVISION A
22 FEBRUARY 1991

CONTRACT NO. F33600-88-D-0567
CDRL SEQUENCE NO. 19A009

MCDONNELL DOUGLAS
McDonnell Douglas Missile Systems Company
St. Louis, Missouri 63166-0516 (314) 232-0232

INDEX OF PAGE CHANGES TASK ORDER NO. 15 DDB				
REVISON DATE AND LETTER	PAGES AFFECTED			REMARKS
	REVISED	ADDED	REMOVED	
02-22-91-A	TITLE PAGE 572	I		INCORPORATE CUSTOMER COMMENTS

EXPERIMENTATION TAGUCHI SET UP

GTE experimentation consisted of the taguchi array L(4)L(9). This is an L(9) outer array with an L(4) inner array. 36 runs are needed for the experimentation [L(9) * L(4)]. Two seeds were used for each experiment and the results averaged for a total of 72 runs.

The L(9) array consists of 4 factors at 3 levels each. The factors and levels are:

Factor L(9) 1: Manpower

- Level 1: As Is
- Level 2: Decrease by 10%
- Level 3: Decrease by 20%

Factor L(9) 2: Workload

- Level 1: As Is
- Level 2: Increase by 50%
- Level 3: Increase by 100%

Factor L(9) 3: Reject rate at final test

- Level 1: As Is
- Level 2: Decrease by 50% (to 12%)
- Level 3: Decrease by 100% (to 0%)

Factor L(9) 4: Work in Process - for GTE subcomponents

- Level 1: As Is
- Level 2: Create initial floating stock to 10% of average WIP
- Level 3: Create initial floating stock to 30% of average WIP

The L(4) array consists of 2 factors at 2 levels each. The factors and levels are:

Factor L(9) 1: Moving much of the bearing housing work in-house to GTE

- Level 1: As Is
- Level 2: Moving in house

Factor L(9) 2: Inductions

- Level 1: As Is in model-inductions randomly through the month.
- Level 2: Inducting all GTEs at day 1 of each month

EXPERIMENTATION - PRELIMINARY RESULTS

The following section describes the results shown by examining the inputs to and the outputs from experimentation:

BEARING HOUSING - Moving the bearing housing in-house makes sense because of the large amount of time the parts sit in backshops waiting to be worked. Moving the work in house can remove most of the waiting time since the part is now most worked under GTE control. The results effect flowtimes of the bearing housing, but not the overall GTE flow times because other subassemblies have longer flowtimes.

INDUCTIONS - Inducting the GTEs at the beginning of the month adds about 4 days to the flowtime, since there is a large number of GTEs at once waiting for disassembly [but excluding the time spent waiting for subassemblies, processing flowtime increases by about 40%]. It is better to spread the inductions over the course of the montn. Weekly inductions would ease the strain on inducting large numbers at the beginning of the month.

MANPOWER - Manpower was reduced for in-house personnel in building 329. While the 10% reduction showed little effect , a 20% reduction shows an effect. Mainly the incoming inspectors are affected, since they are the highest utilized in the model.

WORKLOAD - Increasing the workload by 50% has little effect, but increasing it by 100% has a large effect. Again, the incoming inspectors are they bottleneck. If the workload were to increase above 50%, either the inspectors will have to inspect faster or their number should be increased. It appears from the historical data that personnel in the MATPNC area do much of the inspection of the parts anyway. If the workload were to increase, PNC may be able to formally share in the inspection of the parts.

REJECT RATE - Decreasing the reject rate improves the model flowtimes. The effect is small because the most of the flowtime for a GTE is spent waiting [in the model] for its subcomponents. While the effect in the model is small, the effect on the GTE production process would be large because of the scrambling that occurs at the end of every month to meet the monthly production goals.

WORK IN PROCESS - Finished subcomponents were put into the model to show the effect of overinducting GTEs so that a "good" part can be stripped off a GTE in order to put on a GTE that is almost ready to be sold. The effect is to reduce the overall flowtime for a GTE, but to increase the overall number of subcomponents in the model. When over-induction occurs over a large period of time, a large amount of work in process occurs.

SUMMARY

Much of the effects from experimentation were obscured by the fact that most of the flowtime for a subcomponent is spent sitting idle. Less than 5% of the time is needed for processing. Most of the idle time is spent in backshops that GTE has no control over. The historical data suggests that the excessive flowtimes are due to a lack of

INDUSTRIAL PROCESS IMPROVEMENT ENGINEERING SERVICES PROCESS CHARACTERIZATION TASK ORDER NO. 15

VOLUME V
SA-ALC

CONTRACT SUMMARY REPORT
14 DECEMBER 1990

CONTRACT NO. F33600-88-D-0567
CDRL SEQUENCE NO. 15A008

MCDONNELL DOUGLAS
McDonnell Douglas Missile Systems Company
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PREFACE

This report summarizes the findings and recommendations of the MCDonnell Douglas Missile Systems (MDMSC) Industrial Process Improvement (IPI) team performing Task Order No. 15 at the San Antonio Air Logistics Center (SA-ALC). All work was performed as per the Task Order No. 15 Statement of Work (SOW), the IPI general SOW, and the MDMSC Task Order Proposal. The period of performance was 16 July 1990 to 14 December 1990.

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TASK ORDER NO. 15
PROCESS CHARACTERIZATION

EXECUTIVE SUMMARY

The McDonnell Douglas Missile Systems Company's (MDMSC's) work under Task Order No. 15 was conducted at SA-ALC from 16 July 1990 through 14 December 1990. As called for in the SOW, a Universal Depot Overhaul Simulator (UDOS) 2.0 model of the repair process for the -180 and -397 Gas Turbine Engines (GTEs) was constructed and a detailed engineering assessment of the repair process was conducted. As a result, MDMSC was able to recommend three process improvements as Quick Fixes (QFs) (requiring little or no capital investment) with a savings potential of $2,242,130. MDMSC also recommended two focus studies with potential annual savings realized by establishing a Just In Time (JIT) flow in the GTE repair process and developing a Statistical Process Control (SPC) program to reduce rework. These focus studies will require additional SA-ALC manhour expenditures to complete. Three additional observations were made as process improvement recommendations but which could not be adequately quantified for presentation as QF/FSs.

The simulation model was completed on schedule and was used to quantify the results of MDMSC's recommendations. MDMSC has provided over-the-shoulder and formal classroom training to interested members of the SA-ALC engineering community in the use and development of the UDOS 2.0 model. This training was not a contractual requirement but was considered important to long term program success.

MDMSC's assessment of the GTE repair process revealed that 96% of a GTEs flow time is spent in non-productive delays. No resource constraints were discovered to account for this and the problem appears to be one of scheduling rather than capacity. The bulk of this "mystery" delay time is spent in various back shops in the MAT (now LD) and MAE (now LP) divisions at SA-ALC. MDMSC's recommended solutions to this problem included the design of a machine cell in the GTE area and the establishment of a JIT flow.

The GTE community is currently experiencing high failure/rework rates (24% for FY90) at the final test operation, as well as lower than expected field lives. This problem is attributable to both the GTE repair process itself and to the obsolete and extremely variation-sensitive design of the two GTEs studied. MDMSC recommends the institution of an On-Condition Maintenance Program, to replace the current labor-

intensive overhaul process and the use of SPC to identify and track critical tolerances and the processes which maintain them.

MDMSC did not specifically address wartime surge requirements, as these were analyzed in some detail under Task Order No. 1. No significant process changes or capital investments (with the exception of the new cleaning line, which is still under construction) have been made in the GTE repair process since Task Order No. 1.

8.0 INTRODUCTION

This report summarizes MDMSC's process characterization of the repair process of the -180 and -397 Gas Turbine Engine (GTEs) as it is performed at the San Antonio Air Logistics Center (SA-ALC), Kelly AFB, Texas. This process characterization was performed in accordance with the applicable general Statement of Work (SOW), the Task Order No. 15 SOW, and the MDMSC Task Order No. 15 proposal.

Process performance data was collected by MDMSC engineers and input to the UDOS 2.0 depot simulation model developed under Task Order No. 1 of the Air Force Industrial Process Improvement Program. This simulation model was validated in accordance with the applicable Acceptance Test Procedure. The model was used to analyze the current As-Is GTE repair baseline at SA-ALC and evaluated the impact of proposed changes. This analysis included the identification of critical resource constraints and areas of potential improvement.

In addition to the simulation work, MDMSC performed an engineering assessment of the current operations and resources within the GTE repair process. The MDMSC on-site engineering staff was supported in this effort by the following specialists:

- One Fluorescent Penetrant Inspection Specialist
- One commercial aircraft maintenance expert from Embry-Riddle Aeronautical University (ERAU)
- One Chemical Engineer

The on-site technical team consisted of three industrial engineers, one mechanical engineer, and one computer simulation specialist.

Two of the primary Resource Control Centers (RCCs) in the GTE repair process (MATPGB and MATPSI) were modeled previously under Task Order No. 1. Wherever possible, the validated data collected during Task Order No. 1 was used in the performance of this task order (after SA-ALC engineering review). This task order differed significantly from any performed under Task Order No. 1, however. Rather than study the operation of a single RCC, this task order studied the entire flow of two end items (the GTEs) through all of the RCCs that perform repair work on those items.

This approach (selected by SA-ALC engineers) offered a number of advantages over the traditional method:

- It made the identification of the end-item critical path possible.
- It prevented the development of "sub-optimal" recommendations, which improved the performance of some RCCs but did not improve the overall performance of the depot itself.
- It allowed the identification of "mystery" delays in end-item flow, where items waited for no apparent reason.

MDMSC recommends that this approach be used in future task orders wherever feasible.

Because the structure of this task order differed from the standard model, the format of this report has been modified accordingly. Rather than describe the technology, resources, and processes found in an entire RCC, this report describes those factors for each of the primary RCCs involved in the repair of the selected GTEs. The paragraph on "Specific Process Concerns" describes those concerns which MDMSC judges as significant to the repair of GTEs at SA-ALC.

During the performance of this task order, SA-ALC was reorganized, with new office symbols assigned to many areas. Because the old office symbols are called out in the Task Order No. 15 SOW and proposal, MDMSC has elected to continue their use. The division previously known as MAT is now designated LD.

8.1 GTE OVERHAUL PROCESS

In accordance with the Task Order No. 15 SOW, MDMSC has analyzed and modeled the complete flow of two GTEs through the entire overhaul process. This paragraph documents MDMSC's findings and describes the results of the simulation model.

The GTE's flow was tracked through nine different RCCs, including two dedicated to GTE work (MATPGB and MATPSI) and seven back shops. While each GTE is disassembled into roughly 65 subassemblies, MDMSC concentrated on 17 subassemblies which were selected by SA-ALC personnel as critical. Table 8.1-1 shows the breakout of these critical parts by GTE.

The current repair process used for GTEs is 100% overhaul. Each GTE is disassembled to its component parts, which are then cleaned, inspected, repaired (or replaced), and reassembled into a new GTE. This new GTE is then tested and (if it passes) shipped to the field. Figure 8.1-1 shows the generic process flow for a GTE.

It is misleading to talk about the flow of <u>one</u> GTE, as individual GTEs lose their identity following the disassembly step and never actually regain it. The scheduling system produces the <u>appearance</u> of individual engine flows by removing the serial number plate at disassembly and affixing it to a "new" GTE (one which may have absolutely no parts in common with the original) during assembly. This practice is absolutely unheard of in commercial aviation (Civilian Federal Aviation Regulations forbid it) and is extremely questionable in the SA-ALC GTE process. MDMSC identified this practice in Task Order No. 1 and strongly recommended that it be discontinued immediately. It remains in effect and <u>MDMSC repeats the recommendation that it be discontinued.</u> This is discussed further in Paragraph 8.3.1.1 of this report.

Figure 8.1-2 illustrates the actual "flow" of GTEs through the overhaul pipeline. As shown there, GTEs are disassembled and allowed to enter an enormous inventory of untracked, unscheduled, and uncontrolled GTE parts. Some order is re-established when parts are kitted in the parts pool, but no one has any idea of the real condition of the parts in the parts pool, or how long they have been there. According to the final assembly log data examined by MDMSC, 184 parts from the parts pool were rejected at final assembly during a three month period (June - Sept 1990). This problem is discussed further in Paragraphs 8.1.2 and 8.3.1.2 of this report.

GTE CRITICAL PARTS BREAKDOWN
TABLE 8.1-1

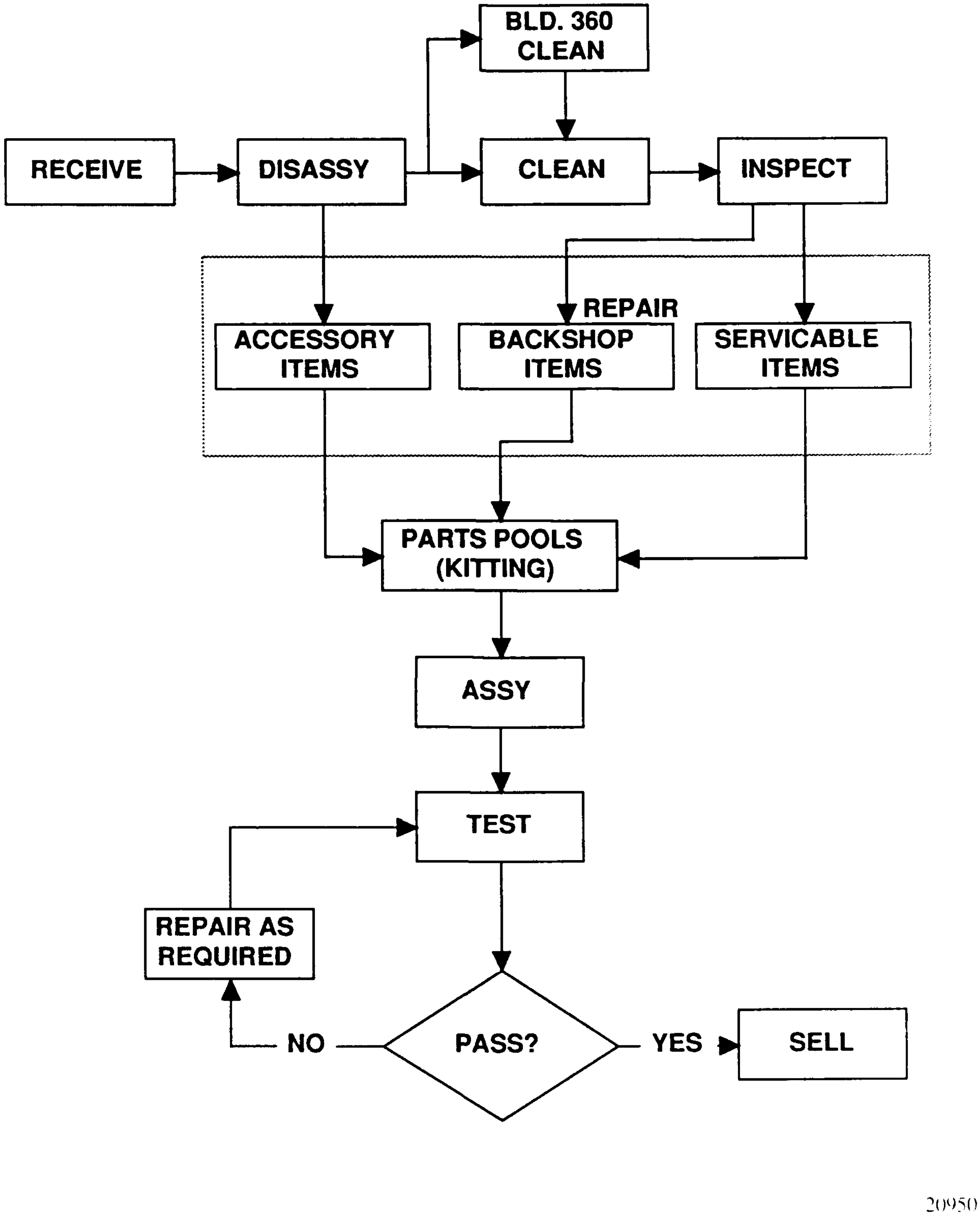
GTCP85-180

ITEM	P/N
Combustion Chamber Liner	899244-3
Turbine Torus	968959-2
1st Stage Inlet Assembly	698197-1
2nd Stage Compressor Housing	698198
Wheel and Shaft Assembly	3606982-1
2nd Stage Diffuser Housing	698195-1
Turbine Nozzle	968886-1
1st Stage Compressor Diffuser	698194-1
2nd Stage Compressor Diffuser	892290-1
Bearing Housing	696659-160

GTCP85-397

ITEM	P/N
2nd Stage Housing	372647-100
Deswire	76443
2nd Stage Diffuser	373823
Accessory Drive Housing	372896-16
Compressor Inlet	376283-20
Turbine Nozzle	378513-4
Turbine Bearing Housing	373237-200, 250

20993



GTE GENERIC PROCESS FLOW
FIGURE 8.1-1

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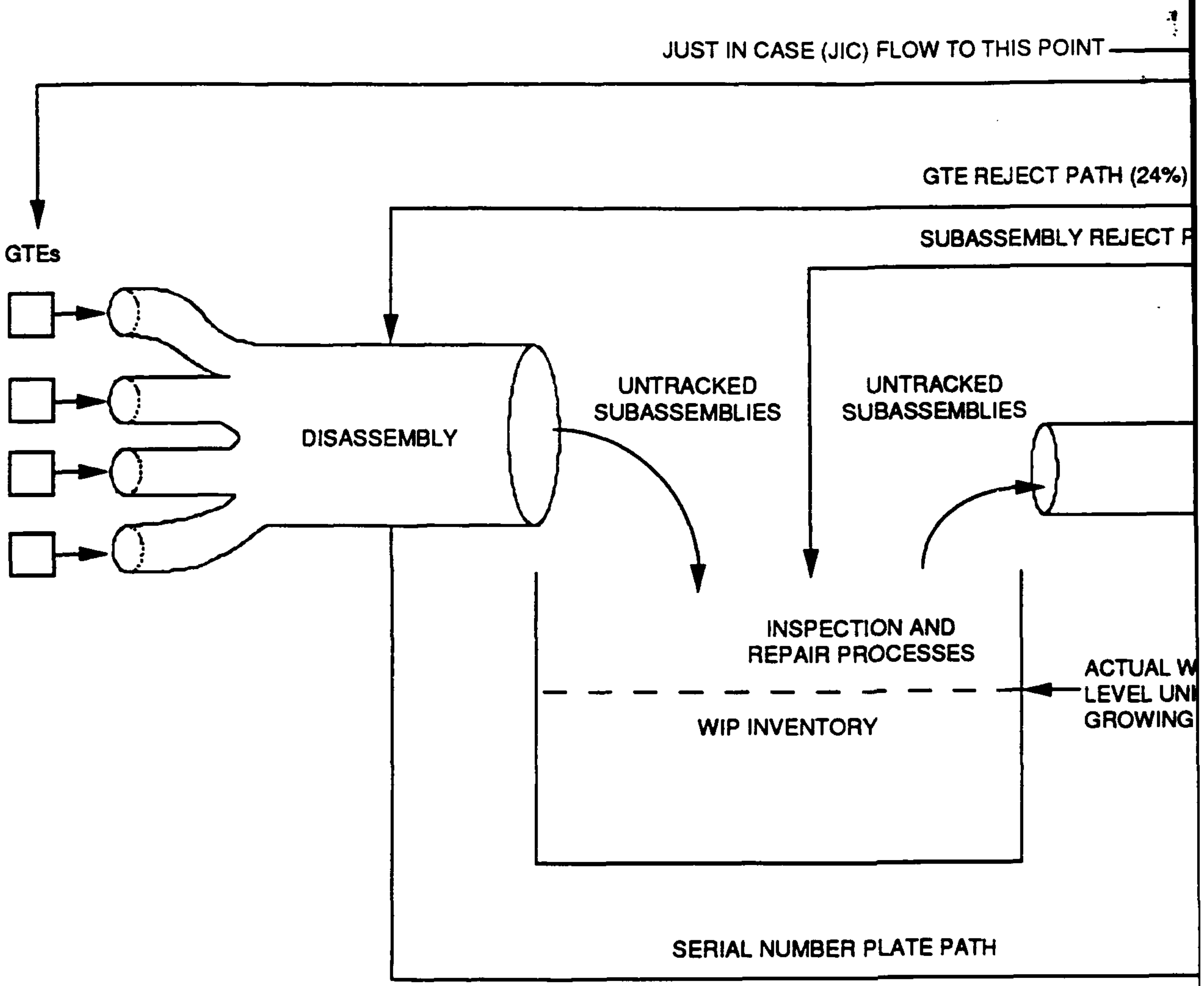
TASK ORDER NO. 15
PROCESS CHARACTERIZATION



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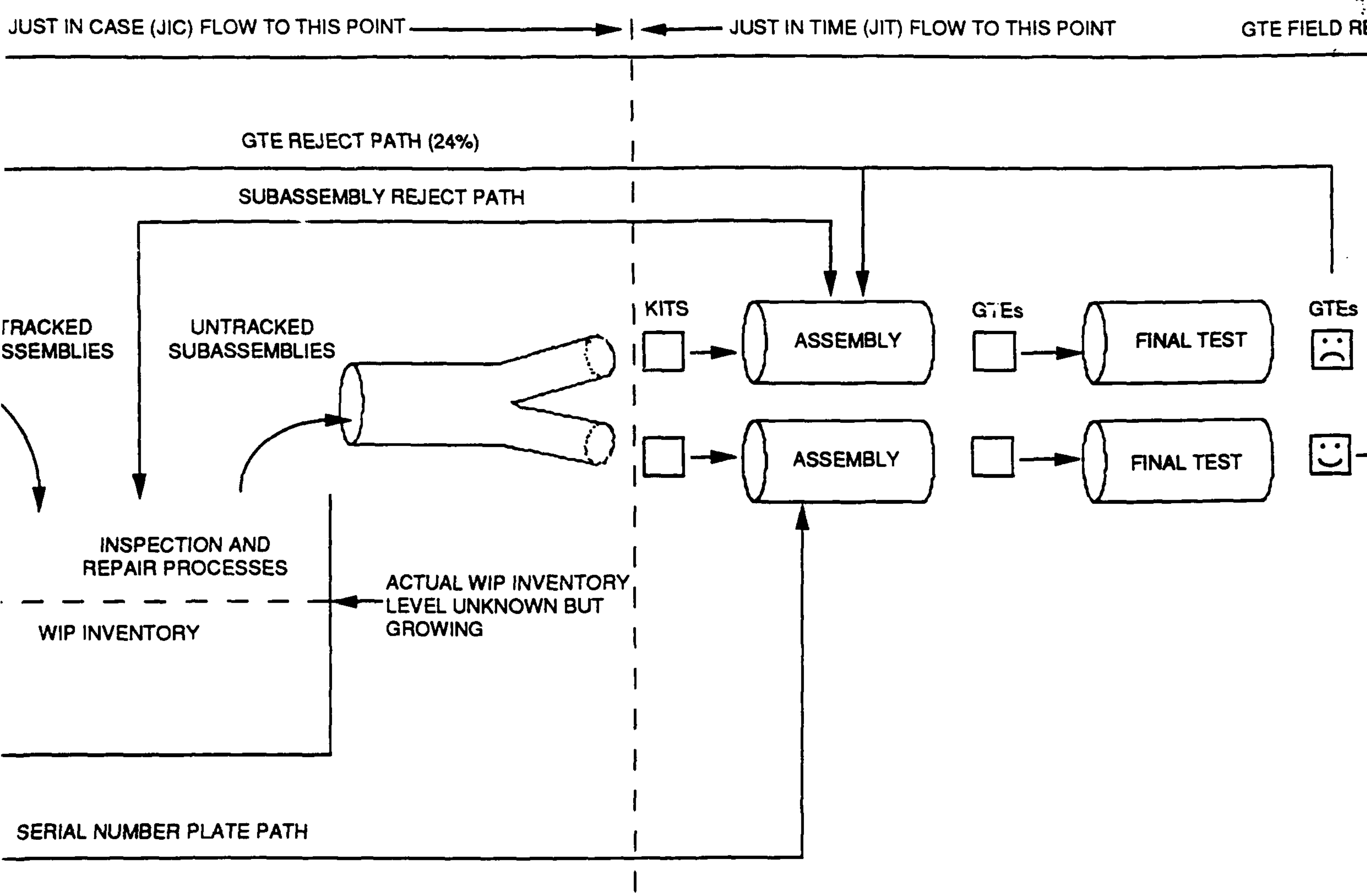
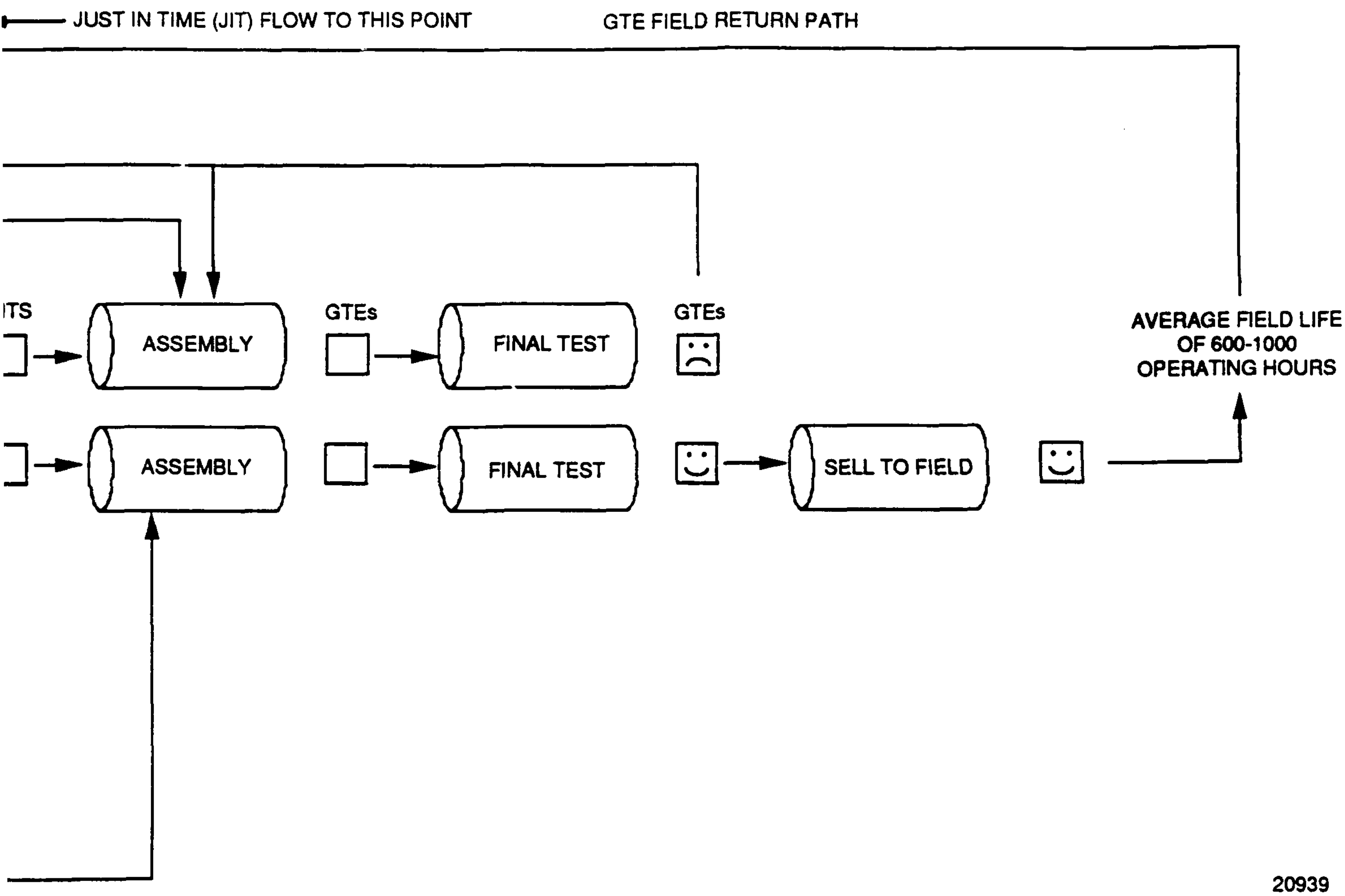


JUST IN CASE (JIC) FLOW TO THIS POINT
JUST IN TIME (JIT) FLOW TO THIS POINT
GTE FIELD RE
GTE REJECT PATH (24%)
SUBASSEMBLY REJECT PATH
KITS
ASSEMBLY
GTEs
FINAL TEST
GTEs
TRACKED
SSEMBLIES
UNTRACKED
SUBASSEMBLIES
ASSEMBLY
FINAL TEST
INSPECTION AND
REPAIR PROCESSES
ACTUAL WIP INVENTORY
LEVEL UNKNOWN BUT
GROWING
WIP INVENTORY
SERIAL NUMBER PLATE PATH

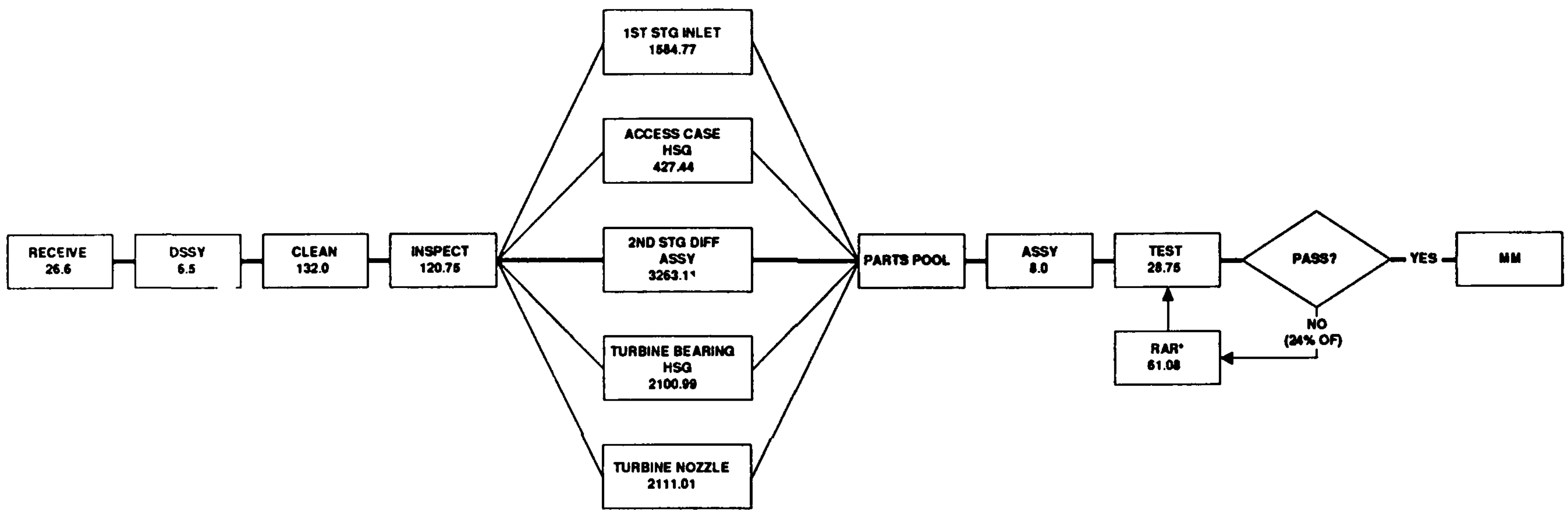


GTE DEPOT PIPELINE FLOW
FIGURE 8.1-2

The GO19C report currently shows the flow time for the -180 GTE as 39 days and the -397 as 40 days. This has been the standard since 1987, when the numbers dropped from 95 days and 93 days respectively (for no apparent reason - the process is virtually unchanged). This "standard flow time" has nothing to do with the actual time required to overhaul GTE, but rather, represents the scheduled time between moving a serial number plate from disassembly to final assembly. The UDOS 2.0 simulation model (constructed using actual historical flow data from FY 90 PAC-stamped Work Control Documents (WCDs)) shows the actual average flow times as 133 days for the -180 and 147 days for the -397.

The bulk of these four to five month flow times are spent as subassemblies in various back shops. Figures 8.1-3 and 8.1-4 show the critical path and pacing item for each engine. The bulk of the back shop time is spent waiting, not being repaired. Figure 8.1-5 shows the relationship between actual production time and non-productive delay times in the back shops for each critical part. Overall, according to the UDOS model, these GTEs spend an average 2.6% of their time being repaired and 97.4% waiting on something. The primary sources of these enormous delays are the huge GTE inventory levels maintained at SA-ALC and the GTE process dependency on multiple functionally-organized back shops. MDMSC's recommendations regarding these situations are described in Paragraph 8.3.1.1 of this report, and Paragraph 8.1 of the Quick Fix Plan.

SA-ALC is beginning to experiment with On-Condition Maintenance (OCM) for some GTEs. Under this system, individual GTEs are kept intact and only those subassemblies which are determined to have failed (or are worn past operating limits) are replaced. <u>MDMSC strongly recommends that this effort be continued and expanded to include the entire GTE population</u>. While no GTE data is available yet, the OCM process is currently used in MATPFA to repair the F100 unified fuel controls with excellent results, as well as by Corpus Christie Army Depot (CCAD) for their turbine engine repair. MDMSC estimates the OCM process will reduce actual average GTE repair costs by 40 - 60% and produce similar (or higher) levels of quality/field reliability. According to SA-ALC engineers, the current 100% overhaul process was designed to alleviate a high rate of field failures/rejects occurring under OCM. MDMSC's analysis of field return rates (measured in clocked operating hours) however, shows that the average operating life between major depot overhauls is only

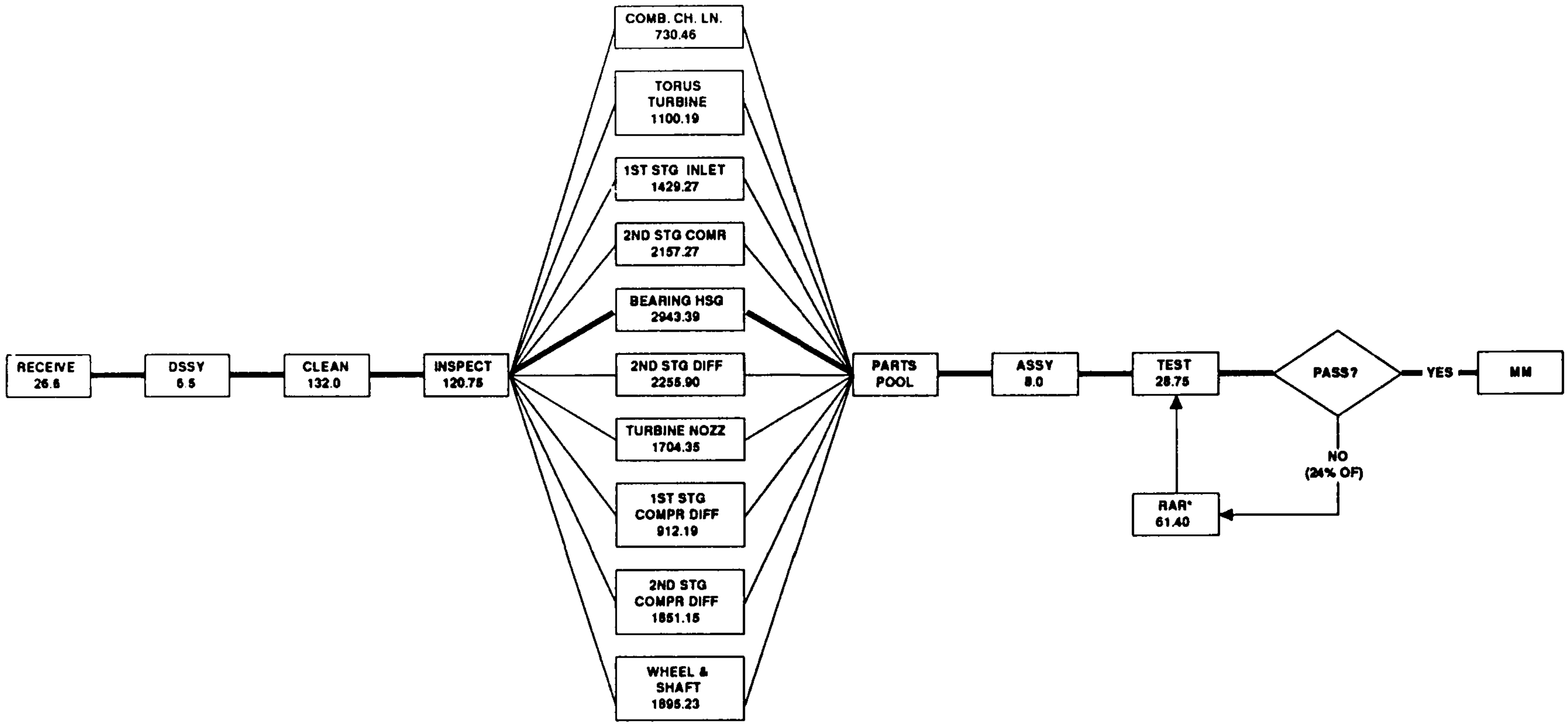


NOTE: PROCESS TIME (IN HOURS) ARE SHOWN IN EACH BOX. THE HEAVY LINE INDICATES THE CRITICAL PATH FOR THE -397 GTE. THE 2ND STAGE DIFFUSER ASSEMBLY IS THE PACING ITEM ON -397 PRODUCTION, WITH ONLY 6 HOURS OF THE 3263 FLOW HOURS ACTUALLY SPENT IN WORK.

* RAR: REPAIR AS REQUIRED

20940

-397 GTE CRITICAL PATH
FIGURE 8.1-3

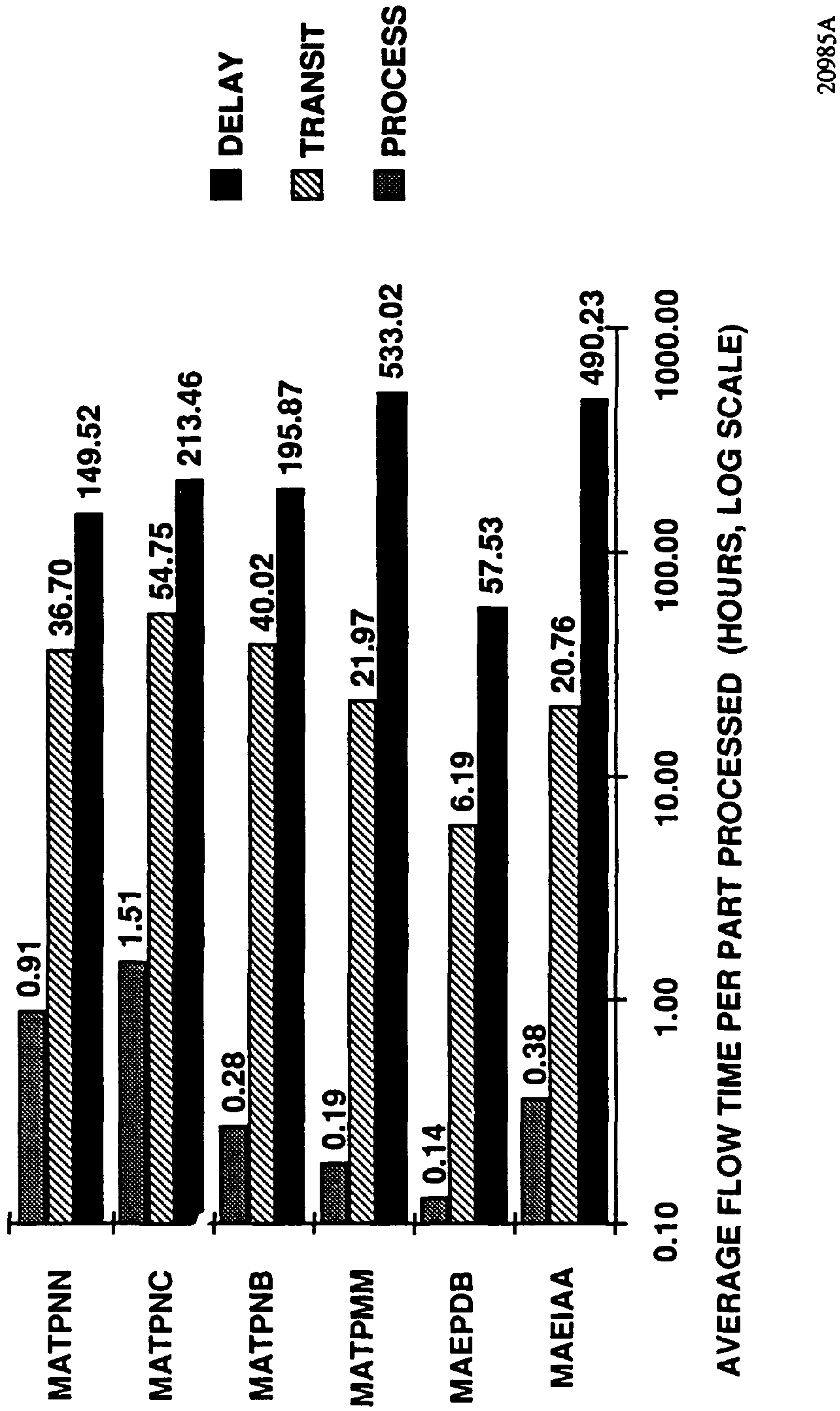


NOTE: PROCESS TIME (IN HOURS) ARE SHOWN IN EACH BOX. THE HEAVY LINE INDICATES THE CRITICAL PATH FOR THE -180 GTE. THE 2ND STAGE DIFFUSER ASSEMBLY IS THE PACING ITEM ON -180 PRODUCTION.

* RAR: REPAIR AS REQUIRED

20941

-180 GTE CRITICAL PATH
FIGURE 8.1-4



AVERAGE BACK SHOP FLOW TIMES
FIGURE 8.1-5

1000 hours for the -180 and 650 hours for the -397. 100% overhaul is obviously not producing the desired quality/reliability any more than OCM did. The actual sources of quality/rework problems are discussed in Paragraph 8.1.2, while MDMSC's recommendations are detailed in Paragraph 8.3.1.2 of this report.

8.1.1 GTE Overhaul Operations Descriptions

The following paragraphs describe the details of the primary individual operations in the GTE overhaul process. They include the operations performed in MATPSI and MATPGB, as well as descriptions of the principle back shop operations.

8.1.1.1 Disassembly Operation

Engines are disassembled in the MATPGB disassembly shop located in Building 329. They are brought in from a storage area located in a different building. Each engine is mounted on a stand while a mechanic strips it into its separate components. The parts are placed together on a cart which is then removed from the disassembly area into a staging area where the parts are prepared for cleaning.

Manpower currently consists of nine workers. There are six WG 10s, one WG 9, and two WG 5s. The WG 5s are used as helpers, primarily for uncrating and routing. The remaining workers (WG 9 and WG 10s) perform the engine disassembly. At this time the disassembly area is only working one shift (day) and overtime is rare. This area is not having problems in keeping up the production rate. The labor force is more than adequately skilled and trained to perform the disassembly operation, and if anything, is probably overskilled for the work they are doing. The manpower distribution in MATPGB is such that WG 10s are used to disassemble the GTEs and WG 9s are used to assemble them. This is exactly the opposite of the situation common in similar commercial operations, and leads to MDMSC's recommendation in Paragraph 8.2. that some of these craftsmen be retrained as inspectors. The equipment in use consists of engine stands and hand tools. One engine stand is used for each engine for the disassembly process. Given the simple nature of the work involved, the equipment condition and quantity appear to be adequate for the job.

The technology used for the disassembly process is adequate. Because the process is so basic in nature, the current manual processes are unlikely to be improved through the insertion of additional technology. On average it takes a craftsman about 1 - 1 1/2 days to disassemble a GTE.

The current labor standard for the disassembly of the 180 GTE is 8.68 hours and 10.90 hours for the 397 GTE. Flow through the disassembly area is smooth. Any delays normally occur at the end of the process where parts are segregated and loaded into cleaning modules. At this point, slight delays sometimes occur until sufficient quantities of similar material parts accumulate to fill the cleaning modules. The addition of the new automated cleaning line in Building 329 will eliminate this delay by allowing immediate cleaning of most parts without the assembly of cleaning modules.

8.1.1.2 Cleaning Operation

GTE cleaning is performed in a two phase process. The first phase involves a pre-cleaning using the automated cleaning line in Building 360. Prior to sending them to Building 360 the GTE parts are segregated by material type and loaded into large cleaning modules. The modules are labeled with a tag specifying the cleaning process required. After the modules are filled they are placed in a holding area awaiting pickup and transportation to Building 360. There they are run through one of the automated cleaning lines and returned without being removed from the module. The entire round trip to Building 360 takes nine to ten days on the average. They return to Building 329 just outside of the disassembly area. The modules are broken apart and secondary cleaning is completed by MATPSI personnel in Building 329. The secondary cleaning in MATPSI is done primarily using manual processes (soaking, wire brushing, abrasive blasting).

MATPSI cleaning is now undergoing a major improvement to their cleaning process. A new semi-automatic cleaning system has been installed in Building 329, next to the disassembly area. The goal of the new cleaning line is to reduce the dependence on Building 360 by bringing the cleaning workload into Building 329 and under the control of MATPSI. With the opening of the new line, only large parts will be sent to Building 360 for cleaning. All other parts will be cleaned in-house. With the new cleaning system, parts will be individually tagged according to material type and cleaning process required. After tagging, parts will be placed in small baskets and are

rolled out of the disassembly area on a conveyor system that feeds directly into the cleaning line. Once on the cleaning line conveyor, the parts baskets are removed using electric hoists. Parts are then dipped into the proper tanks by the hoist operator. Once cleaned, the parts and baskets are moved over to the inspection area where they are prepared for Fluorescent Penetrant Inspection (FPI) and Magnetic Particle Inspection (MPI).

There are currently 11 WG 5s working in the MATPSI cleaning area. At the moment there is only one shift (day) and there is about 20 hours of overtime worked per month for each employee. The skills required for the cleaning process are generally low, however, there appears to be a shortage of manpower in the cleaning line. This is evidenced by the backlog of parts scattered throughout the cleaning area. This situation was identified during Task Order No. 1, and a second shift recommended. It is difficult to predict whether or not manpower will be sufficient for the new cleaning line, as not enough is known about how efficient or labor intensive the new cleaning process will be.

The new cleaning line consists of two vapor degreasers, two dip tank lines, a drying oven and two post-cleaning inspection areas. There are also several abrasive blast booths and paint stripping booths.

The old cleaning line is inadequate for proper cleaning of the GTE parts. It was intended as a touch up process for the cleaning line in Building 360. The cleaning capabilities of the automated line in Building 360 area is questionable, however, and the "Touch Up" required afterwards is considerable. The new line represents a marked improvement over the old, however, some problems appear to remain. The tanks and conveyor baskets are not large enough to clean the larger GTE components, which must still be cleaned in Building 360. In the grit blast and paint removal areas the current walnut shell and plastic media methods are slow and leave some residue on the parts. Leakage from the booths tends to contaminate the surrounding areas and reduces air quality. The installation of CO_2 blasting equipment would reduce a large portion of these problems, improve cleaning quality, reduce cleaning times, and eliminate the requirement for vapor degrease. This suggestion is

discussed further in Paragraph 8.1.3 of this report. The current labor standard for the cleaning in MATPSI is 10.91 hours to clean the 397 GTE and 13.96 hours for the 180 GTE.

8.1.1.3 Inspection Operation

Parts are inspected in Building 329 by MATPSI Inspection personnel. Immediately after cleaning in MATPSI most GTE parts are routed to the Fluorescent Penetrant Inspection (FPI) area in Building 329. Those parts that require it are prepped for FPI by manual dipping and rinsing operations. Once penetrant is applied, the parts are moved by conveyor to a climate controlled room where they are inspected. At this time those parts requiring Magnetic Particle Inspection (MPI) are also prepped and inspected at booths in the area. Once Non-Destructive Inspection (NDI) inspection is complete the parts are identified, paper work is attached, and the parts sit for a minimum of 24 hours for a temperature acclimation period. The parts are then loaded into plastic baskets and are moved by conveyor into the main dimensional inspection area.

Once inside the dimensional inspection area the parts are distributed to those inspectors and areas that are dedicated to perform the inspection task. After inspection is complete, WCDs are attached and the parts are rolled out of the inspection area via a conveyor. Once outside, the parts wait on the conveyor until they are routed to the appropriate back shops by parts handlers. Parts handlers sort the parts by destination and label the plastic basket with that destination. They are then loaded onto carts and pulled away by a tug. An MDMSC recommendation to expedite parts sorting/handling at this point is described in Paragraph 8.3.2.

There are five WG 10s and ten WG 9s currently working in the GTE section of the inspection area. Of these 15, four of the workers are on loan from other departments. At this time the operation is conducted on only one shift. Overtime is worked occasionally, depending upon the workload.

The work force is sufficiently skilled to perform the inspection task. A skill level of WG 9 is all that is required to perform the inspection work now being done on GTEs. WG 10s are more qualified than WG 9s because they are certified to perform eddie current inspection, however, the eddie current methodology is not currently being used to

inspect GTE parts. The people in the GTE inspection area are very heavily utilized. Any large increase in workload will cause a significant bottleneck in production. Surges in workload caused by DESERT SHIELD, for example, have created a backlog of parts in front of the inspection process. The FPI area is also very highly utilized and any large increase in workload would cause a build up of backlog in this area.

There are a total of 17 workstations in the GTE portion of the inspection area. All the equipment appears modern and in good condition. The FPI line consists of a penetrant dip tank, curing area, manual rinsing booths, a developer dip tank, and drying oven. Sections of the line are connected by sections of roller conveyor. Baskets are dipped using manual hoists. There are two blacklight booths for FPI interpretation and one booth for the MPI process located in the room between the FPI prep area and the inspection area.

The technology of the inspection process is adequate. The FPI methodology is the most cost effective way to inspect used parts for cracks and is in wide use throughout military and civilian industrial centers. The current FPI line requires a great deal of manual effort to operate and would benefit from the MDMSC recommended changes described in Paragraph 8.1.3. The dimensional inspection area has adequate equipment. The APIS systems are technologically advanced and are doing a good job. Flow times through the NDI portion of the inspection process are tough to estimate because it is difficult to track the GTE parts before paper work is attached. Flow data for the process does not exist at this time. The current engineered labor standard for NDI is 5.67 hours for the 397 GTE and 6.33 hours for the 180 GTE.

Flow time through the dimensional inspection area is easier to estimate because paper work is attached to each part after the NDI process. Most parts take about two to three days to dimensionally inspect. However, some parts are very time consuming to inspect and only the minimum requirements are completed. There is currently an accumulation of some "hard to inspect" parts growing in the inspection area. The reason this may be occurring is because of an inequity in the way the various RCCs are paid for their effort. Currently, payment is made for each GTE that is completed at the end of the process. MATPSI is currently being "paid" 8.54 hours to inspect 397 GTE parts and 19.91 hours for 180 GTE parts. However, because many more GTEs are inducted than are actually completed, shops near the beginning of the GTE repair

process are asked to process a significantly higher number of parts than they are being "paid" for.

Currently, most parts are routed to the back shops that are listed on the WCD paperwork, in the order they are listed. Each back shop then inspects the part and either performs the required operations or stamps the WCD operation as not required. The part is then sent on to the next back shop listed on the WCD and the process is repeated. With this routing process it is possible for a part to spend a great deal of time traveling from shop to shop for no reason which may explain some of the mystery time between long flow times and short process times in the back shops. Much of the responsibility for the rework decisions are passed on to the back shop. A considerable amount of flow time could be eliminated if the routing of a part was specified by the inspection area based upon information obtained during the inspection process. Inspection of parts at the completion of the repair process would help to prevent rejects at final test by removing bad parts before they are built into engines. Inspection at this point would also provide valuable feedback to the back shops in a more timely manner in the event of defective work.

8.1.1.4 Back Shop Operations

The bulk of the repair of GTE parts is performed in various back shops. The following sub paragraphs provide brief descriptions of the back shops contributing the most work (and flow time) to the GTE repair process. Figure 8.1.1.4-1 shows the average relationship of process, transit, and delay times in each back shop.

MATPNC - MACHINE SHOP

The machine shop located in Building 303 is responsible for machining processes related to aircraft, aircraft engines, and GTE component repair. The GTE workload in this area has its own dedicated equipment and personnel.

This area has an efficient layout. It is well lit and clean, and items are neatly organized on stainless steel racks located throughout the shop. These racks are an excellent addition to the area, and make it very easy to tell how much work in process (WIP) is present. The fact that certain racks are dedicated specifically to in-coming and out-going parts makes material handling much easier, and contributes to the fact that material transport and handling practices in the area were relatively efficient

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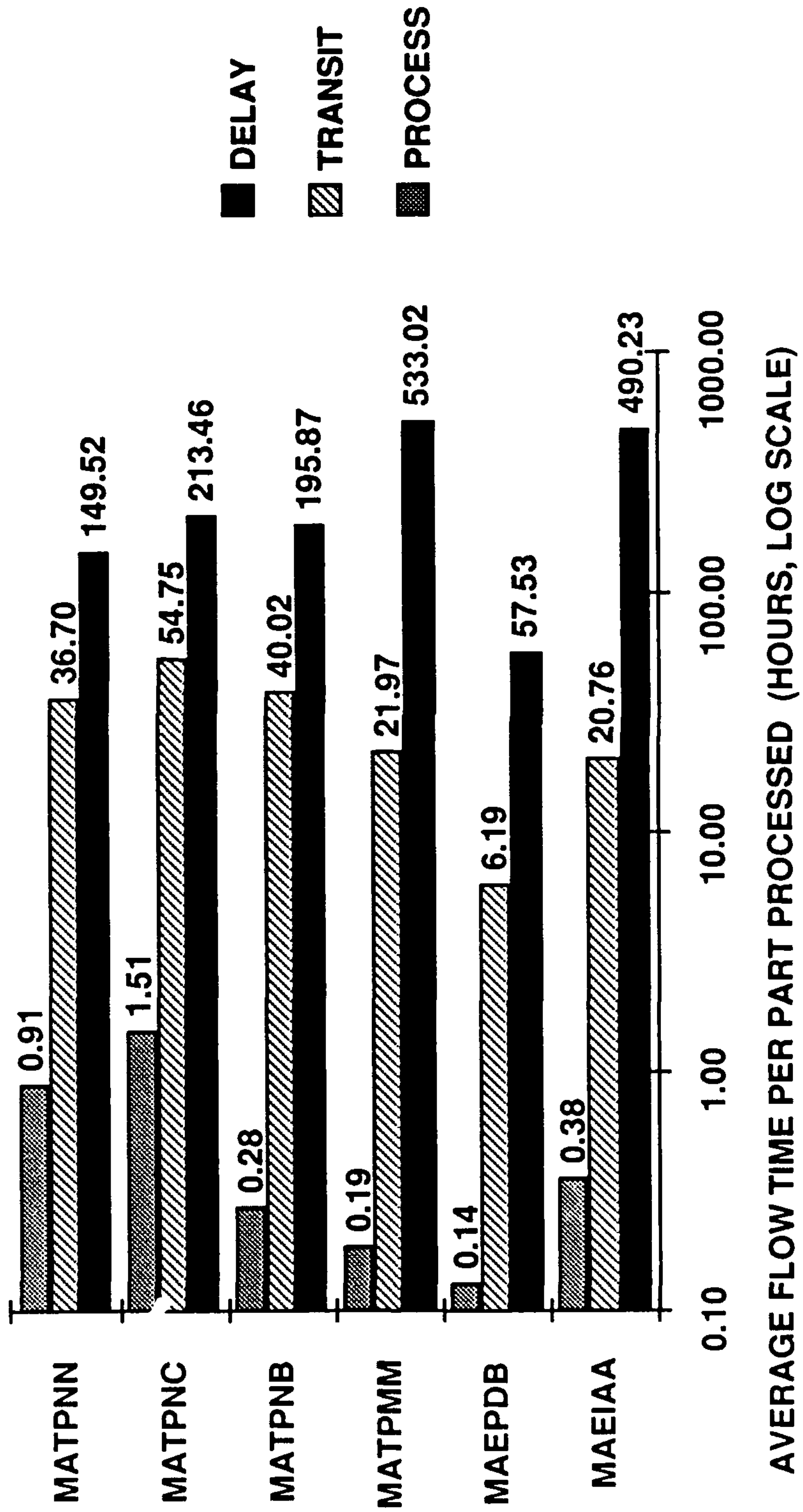


AVERAGE BACK SHOP FLOW TIMES
FIGURE 8.1.1.4-1

The amount of WIP present is substantial. This accounts for the lengthy, historically-documented flow times in this area. This flow time does not have much to do with the actual processing of items in this area, but more with a lack of structured production goals for this area. The individual machinists produce only the number of items necessary to meet the minimal production quotas for GTE end items for each month, however, they receive a significantly larger number of individual components (due to over-inductions) than they produce in a given month. Items become buried under ever increasing WIP, which contributes to the quality problems in the GTE process. Items which are rejected at final assembly may circulate through the system continually, as no records are kept.

MATPNB - FPI

This area is located in Building 303, and performs non-destructive inspection of a variety of items, including GTE components. This back shop function proved to be one of the most efficient at processing items in a timely manner.

The same inspection capability presently exists in-house for the GTE repair process. If machining an/or other repair processes were moved in-house to Building 329, the facility there could be used to process the workload now performed in Building 303.

MATPNN - WELDING

GTE welding tasks divide into two major categories: Build-up processes, including plasma spray, and general sheetmetal repair. The build-up processes are usually closely associated with machining practices, and any movement of parts to an in-house machining process would require associated welding support.

MAEIAA - PLATING

The greatest percentage of plating operations performed on GTE components in this RCC involve anodizing processes. These require pre-cleaning, masking, and a relatively simple tank process, all batch operations which do not require the same items to be processed simultaneously. The process currently used, is a "barrel" plating operation. Other GTE plating processes include chrome plating and hard coat anodizing.

8.1.1.5 Final Assembly Operation

Final assembly for the 180 and 397 GTEs is performed by MATPGB in Building 329. Assembly can be broken down into two basic phases. The first phase consists of the assembly and "stack-up" of the various sub-components of the engines. The 397 GTE is built up in three major sections: the Accessory Case, the Turbine Section and the Compressor Section. The rotating components for the Turbine and Compressor sections are assembled and balanced in the balance shop prior to assembly into their respective sections. The 180 GTE is built up in two sections. The Turbine Section and the Compressor Section are built up as one subassembly and the accessory case is built up as a separate subassembly. After the subassemblies are completed they are stored on shelves until they are needed for assembly into a complete GTE. The various subassemblies are assembled into a complete engine in the second phase of the process. Any additional parts that are needed are obtained from the parts pool. The serial number for the engine is assigned at this point. When the engine is complete it is sent to Building 340 for final test.

There are a total of 15 mechanics in the final assembly area. There are 2 WG 10s and 13 WG 9s. Currently the area is working one shift and they consistently work about 28 hours of overtime per month. The skill level of the mechanics is adequate. As mentioned earlier, MATPGB is currently using WG 10s to disassemble the engines and WG 9s to assemble them. Because engine assembly is more critical than disassembly, it would make more sense to use the WG 10s for the assembly process and WG 9s for disassembly. The current levels of rework (from final test) are the primary source of the overtime. This area is adequately staffed and is not a process bottleneck. It is on the GTE critical path, however, so work stoppages here affect the GTE delivery schedule.

There are four bays which are used to assemble the GTEs, one of which is dedicated to the 180 and 397 GTEs. Up to four engines at one time can be built in each bay, however, this level of production would make the assembly area very crowded and would be difficult to sustain for long periods of time. Hand tools are primarily used for the process and appear adequate. There are several two-plane dynamic balancing machines in the balance shop. The equipment is fairly new and in good condition. There is a sufficient amount of balancing equipment to meet production requirements. Each machine is normally dedicated to the balancing of a particular component.

The technology of the assembly process is adequate, with some possible exceptions. Engine assembly is essentially a manual task using basic hand tools and it is not likely that any major technological improvements can be made. Some improvements, however, can be made in the inspection process during the stackup of sections. Because of the critical effect of alignments and tolerances upon engine performance and vibration levels, improvements could be made in the dimensional measurement equipment. The current balancing method (two-plane dynamic balancing) is the same used throughout the industry. The metal removal technique is crude (grinding) and is basically a trial and error process, however, the craftsmen are able to balance components up to the sensitivity limits of the balancing equipment. Increased machine sensitivity and improved balance quality could be achieved by increasing the rotational speed of some of the balance machines. This could be done inexpensively by installing a larger drive pulley.

Interview data indicates that it takes about 24 - 27 hours to assemble a 397 and about 26 - 37 hours to assemble a 180. The current labor standards to assemble the 397 and 180 are 30.78 hours and 38.54 hours respectively. Usually there is not a large amount of delay time involved with the assembly process. Any engine that is rejected at the test stand is sent back to final assembly where it is stored until there is time to repair it. This delay time can vary, depending upon the availability of a mechanic. Normally it takes about 11 - 15 hours to repair a rejected 397 and about 15 - 19 hours for a 180.

There are some quality problems that became evident at final assembly. Because most parts are not inspected after they are processed in the back shops, defective parts end up in final assembly. Some of the defects are caught by mechanics prior to assembly,however, final assembly lacks the proper equipment to adequately inspect all parts that they receive. Often many defects are not found until some point in the assembly process. Some defects are not caught at all and show up at final test. This is an extremely expensive and time consuming way in which to locate defects. Proper quality control prior to final assembly will reduce test stand rejection rates, reduce assembly times, and provide valuable feedback to back shops.

8.1.1.6 Final Test Operation

Final testing for the 180 and 397 GTEs is performed in Building 340, located directly across the street from the final assembly area in Building 329. When they are ready for final testing, engines are loaded onto carts and moved over to Building 340 where they wait until a test cell is available. When a cell becomes available, an engine is moved in and installed. During this time any manual adjustments that must be made are completed. After installation, the test cell computer system is turned on,and from this point onward, test cell time is logged by the computer. Testing is completely automated and all test information is automatically recorded to a database. The engine is run through a sequence of tests, while any deviations in performance are flagged and recorded. Engines that pass the sequence of tests are removed and sent to an area where they undergo a final inspection and are prepared for shipping. If an engine fails on the test stand a mechanic from final assembly is called in to troubleshoot it. If vibration is a problem, a vibration-frequency power spectrum is recorded and analyzed to help pinpoint the source. If possible, the engine is repaired on the test stand and retested. Engines that cannot be repaired on the test stand are removed and sent back to final assembly.

There are a total of 14 workers in final test. Manpower distribution is 12 WG 10s, 1 WG 9, and 1 WG 7. Ten of the WG 10s are certified as test stand operators. The remaining work force is used for final preparation of the GTEs. Final test is currently operating on one shift. Overtime is worked occasionally, depending upon delivery requirements. The work force is adequately skilled to perform the testing and preparation work and there is sufficient manpower to meet current production requirements.

There are seven active test cells which can be used to test GTEs. Each cell is equipped with a stand alone computer system which is used to perform the automatic testing function. A vibration frequency power spectrum analyzer is available to all the test cells in case of a vibration problem. The test cell equipment is in good condition and adequate. There are a sufficient number of test cells to meet production requirements.

The technology used in final test is modern and efficient. The automated test cells are particularly worthy of praise, as this automation helps to standardize testing procedures and eliminate operator errors. The vibration power spectrum analysis is a

state of the art method for tracking down the sources of vibration problems. The automated system, designed by SA-ALC engineers, is very similar to that used throughout industry and at the Corpus Christi Army Depot (CCAD).

Flow through the final test area is uneven, with cycles of slack periods and busy periods, caused by an unbalanced production schedule. Based upon test cell data for FY 90, the average test cell time per visit for a 180 was 15.41 hours and 13.83 hours for a 397. These figures include an estimated installation time of two hours and an estimated removal time of two hours. Rejected engines spent several hours less time on the stand than did the accepted engines. The current engineered labor standards for final testing of the 180 GTE are 21.30 hours and 19.65 hours respectively. The FY 90 reject rates for the 180 and 397 GTEs were both 24%. This rate was derived from FY 90 test stand data and is calculated by dividing the number of engines that failed at least once by the total number of engines that were eventually accepted.

8.1.2 Specific Process Concerns

This paragraph describes, in detail, specific areas in the repair process for the -180 and -397 GTEs, which MDMSC considers significant concerns. MDMSC's recommendations for addressing these are discussed in detail as process improvement opportunities in Paragraph 8.3 of this report and in the QFP.

8.1.2.1 Process Quality/Rework Rates

The overhaul process for the -180 and -397 GTEs currently appears to be out of control. While no in-process statistics are currently captured, failure data is available from the final test operation, as well as a log of parts rejected at final assembly. This data indicates that subassemblies and assembled GTEs are being rejected and reworked at excessive rates. As no in-process quality data is collected, no one is sure what part(s) of the overhaul process are causing these rejects.

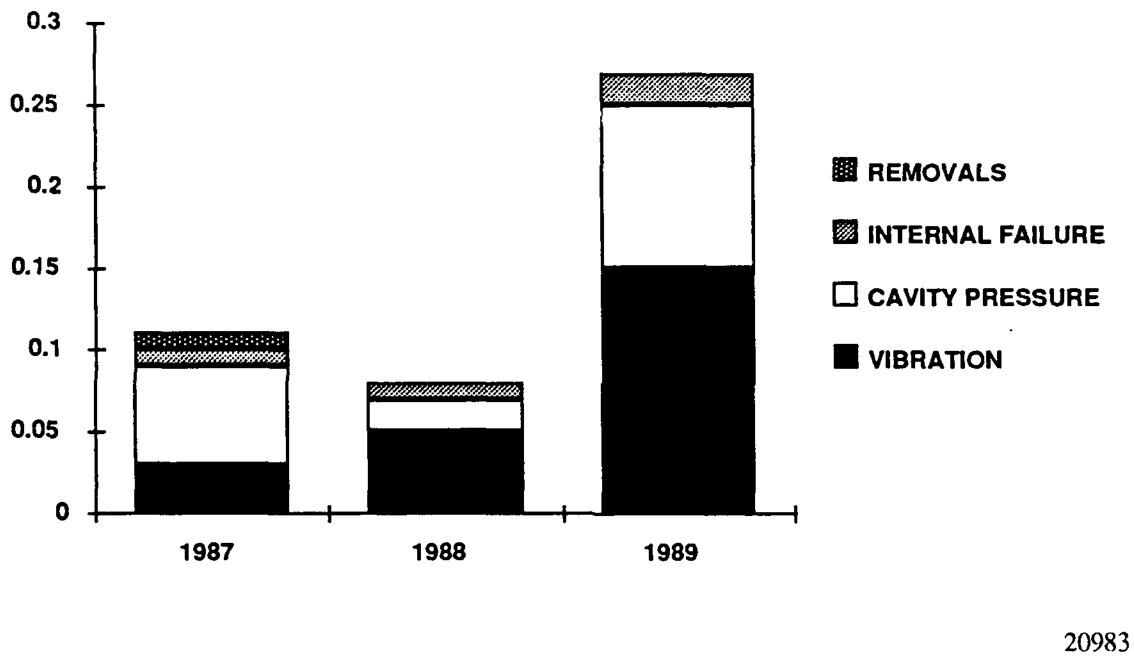
GTE subassemblies go directly from their respective repair processes into the parts pool in Building 324 without any type of inspection. As a result, no one has any idea of the actual condition of the supposedly "serviceable" parts stored in the parts pool. This condition is only determined during the assembly of a GTE, when unserviceable parts must be rejected. Assembly is the second most expensive point in the overhaul process for a reject to occur (the most expensive is final test). As assembly is a critical

path operation, any delay causes a corresponding delay in GTE deliveries. Because the assembly operation receives parts in a Just In Time (JIT) fashion, there is no production slack time between scheduled GTE delivery and delivery of the kit to assembly. This means that every rejected part at assembly causes a slip in the GTE delivery schedule. If the part cannot be cannibalized from another kit, the entire GTE waits while a new part is ordered or expedited through the repair process. According to the assembly logs, 184 parts were rejected in a three month period during June - September 1990.

This situation is acerbated by the lack of parts tracking found in the repair processes and the parts pool. Parts can sit in the parts pool for months (no one really knows how long some parts have been there), before moving to assembly. When a reject occurs, the process problem which produced the unserviceable part may have occurred months previously (and may have continued producing bad parts ever since). There is very little feedback provided to the repair operations and no follow up of process problems by engineering or quality personnel. MDMSC's recommendation involves the addition of an inspection stop after repair and the elimination of the parts pool altogether. The details of these recommendations are described in Paragraph 8.3.1 of this report.

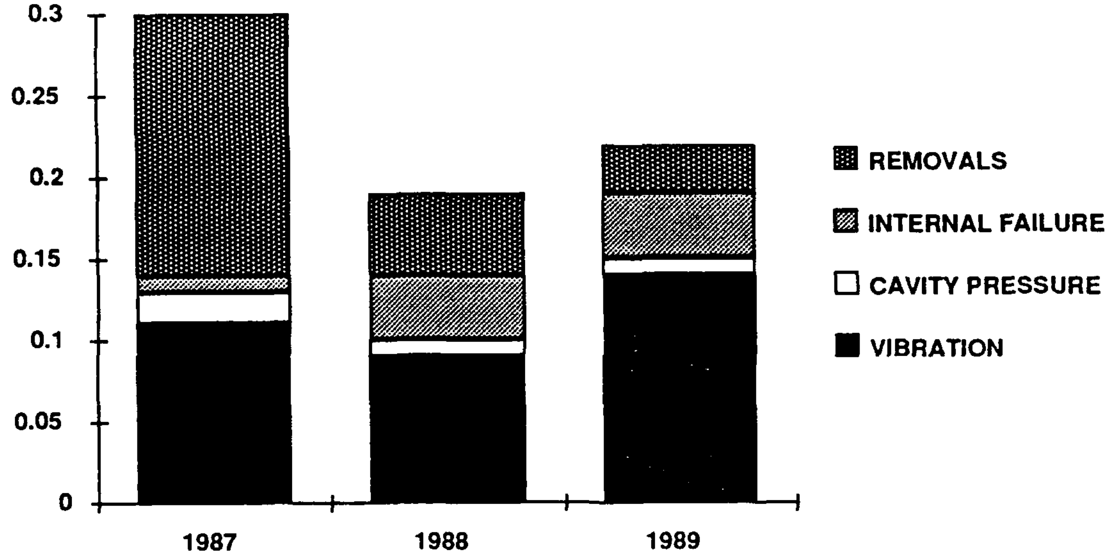
Even worse than a rejected subassembly at the assembly point, is the failure of an entire GTE during final test. At this point, SA-ALC has already made the maximum investment in repairing the GTE. If the GTE does not pass, there is no value-added to the engine in spite of the investment made. The current average rejection rate for both GTEs studied is 24% (for 1990). Figures 8.1.2.1-1 and 8.1.2.1-2 show the history of test rejects since 1987 for both GTEs. The overall reject rate is consistently high, with high variability - symptomatic of an uncontrolled process.

After one to three failures to pass the final test, the GTE is rejected. A rejected GTE is partially or completely disassembled, and repaired as required. Repeat rejects are sent to disassembly where the GTE is disassembled and the serial number plate moved to another engine. Failure data is captured at final test, but is indexed by serial number. This allows the scope of the reject problem to be determined, but renders all actual process output data useless.



-180 GTE TEST REJECT HISTORY

FIGURE 8.1.2.1-1



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-397 GTE TEST REJECT HISTORY
FIGURE 8.1.2.1-2

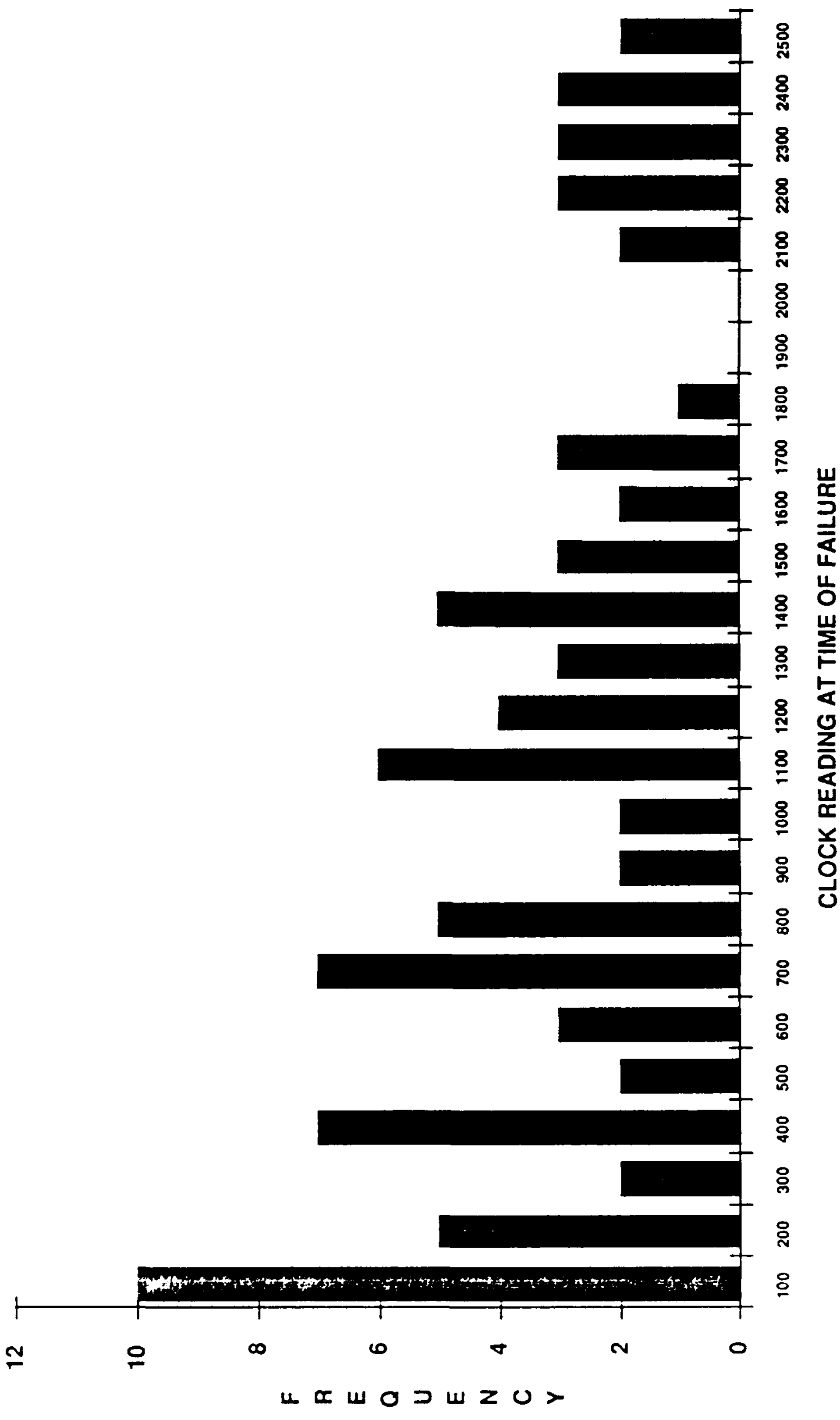
The most common cause of failure at final test is excessive vibration. This situation is described in more detail in Paragraph 8.1.2.2 of this report.

Even worse than failure/rejects within the GTE overhaul process, is a failure/reject occurring in the field, after delivery. According to the logs maintained in disassembly, -180 engines operate an average of 1000 hours in the field, between 100% overhauls, while -397s operate less than 650 hours. This is extremely low, when compared to the operating life of a new GTE (according to Garrett APD - the manufacturer) of 2500 hours for military operations (commercial airlines report over 5000 hours under OCM repair programs). The average, however, does not tell the story. The operating (clock) hours between overhauls tend to cluster heavily at the low end of the scale. The average (mean) is raised by a small number of GTEs which go as much as 9000 hours between overhauls (indicating what the design is capable of if properly maintained). Figures 8.1.2.1-3 and 8.1.2.1-4 show the failure distribution of both engines in 1990. Section 8.1.2 of the Database Documentation Book (DDB) contains similar histograms for 1986 - 1989. They all show similar distributions. If all failures below 100 hours are considered rejects (severe infant mortality) the field reject rates for the -180 and -397 are 8% and 10% respectively, (for 1990.)

No induction inspection or failure analysis is currently performed on GTEs returned from the field, so no data is available regarding trends or patterns of failure. The returned GTEs are simply disassembled and their pieces poured into the repair process. A rejected GTE represents the total loss of all repair process investment plus the cost of round trip shipping and an intangible loss of mission readiness in the field. Table 8.1.2.1-1 shows MDMSC's estimates of the costs of the current test and field reject rates.

8.1.2.2 Excessive Vibration at Final Test

Currently, vibration problems make up an average of 50% of the total average 24% rejection rate for the 397 and 180 GTEs. Of these vibration rejects, 76% are from excessive vibration in the turbine and compressor assemblies (rotating bodies). <u>MDMSC concludes from this, that out-of-balance rotating parts are the single largest source of rejects/rework in the GTE repair process</u>.



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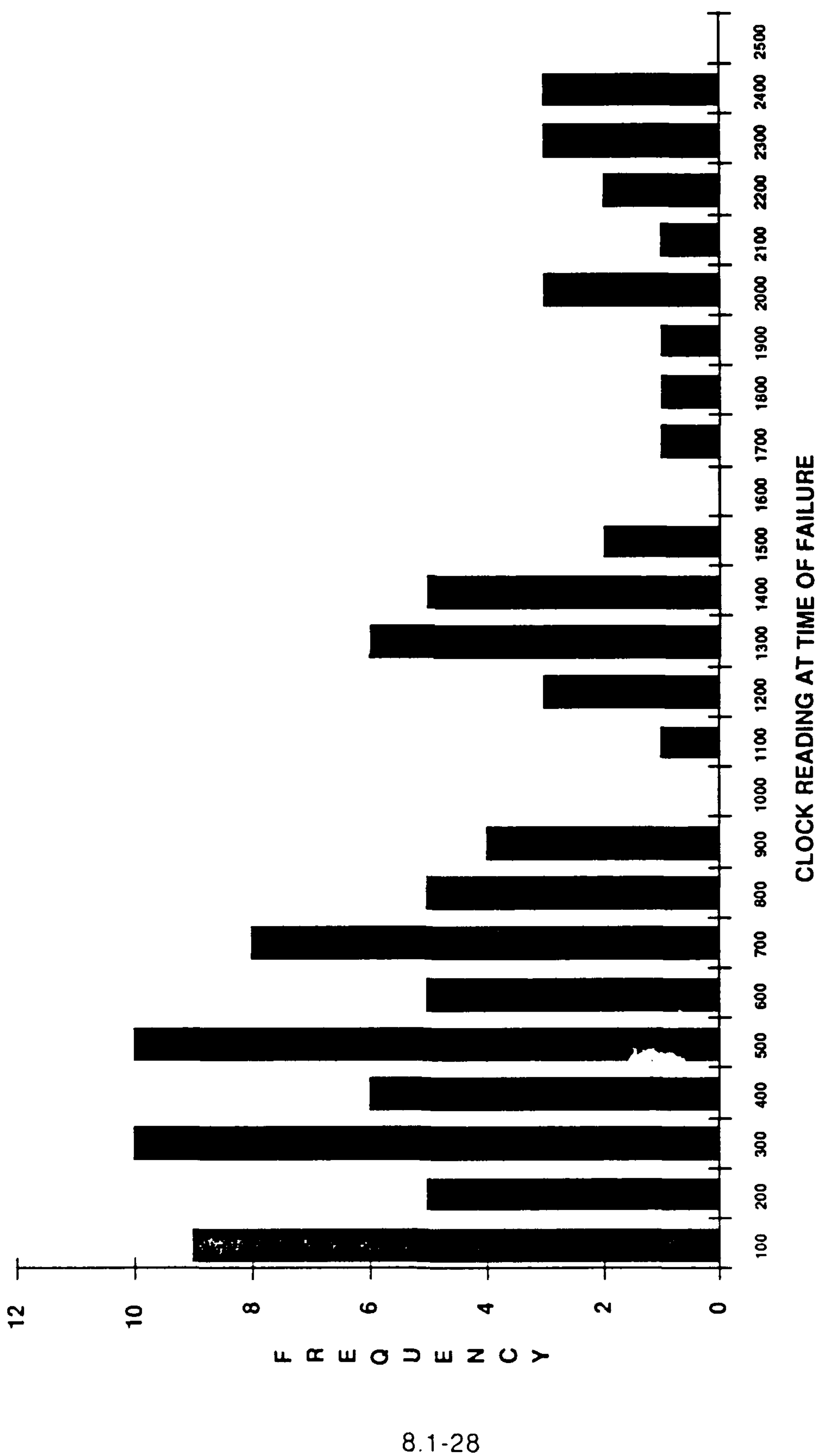
1990 -180 GTE FIELD FAILURE DATA
FIGURE 8.1.2.1-3



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1990 -397 GTE FIELD FAILURE DATA
FIGURE 8.1.2.1-4

GTE REPAIR COSTS
TABLE 8.1.2.1-1

GTE	G019C REPLACEMENT COST	G019C 75%(1) REPLACEMENT COST	REJECT RATE: FINAL TEST(2)	REJECT RATE: FIELD(3)	REJECT RATE: TOTAL	G019C REPAIR COST	MDMSC EST. REPAIR COST(4)
-180	$76,000	$57,000	24%	8%	32%	$33,407	$44,097
-397	$73,123	$54,842	24%	10%	34%	$30,785	$41,520

(1) Repair/Replace break even point

(2) 1990 Test cell data

(3) 1986 - 1990 Field returns at less than 100 clock hours

(4) G019C repair cost plus rejection rate (to reflect cost of rework)

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While Air Force engineers have studied this problem for several years, no systematic data appears to have been collected, and the problem appears to have continued (or even gotten worse) over the last four years. Figures 8.1.2.2-1 and 8.1.2.2-2 show rejection data for these engines since 1987 (the extent of the reject log book data available in MATPGB). An examination of reject rates over the last 12 months, as illustrated in Figures 8.1.2.2-3 and 8.1.2.2-4, shows that this situation is characterized by high variation as well as a high mean average. This extreme variability of the rejection rates indicates that this is an extraordinarily complex problem, with many possible sources of variation. MDMSC doubts that any one factor can be said to cause the problem.

MDMSC concludes that, given the apparent complexity of the situation and the lack of statistical process data, neither MDMSC nor SA-ALC engineers have any definitive idea about what is causing this problem. The only way to learn what is causing the out-of-balance vibration is to conduct a series of scientific experiments, and document the results. MDMSC believes these experiments are critical and recommends that SA-ALC engineers conduct the Taguchi-based experimental procedure described in Paragraph 8.3.3.2 of this report.

Details of the vibration problem can be found in Section 8.3.3.2 of the DDB.

8.1.2.3 Unscheduled Flow of GTEs

GTEs are currently allowed to flow through the SA-ALC repair process with very little attempt at scheduling. Deliveries of finished GTEs are scheduled by number required, but the flow of an individual GTE is untracked and unscheduled. As described in Paragraph 8.1, the "scheduled" flow days (39 for the -180 and 40 for the -397) are a product of serial number manipulation and not of actual GTE production. The UDOS simulation projections of 133 and 147 days for the -180 and -397 are averages for the amount of time required to overhaul an engine when the original parts are kept together. In fact, original parts are not kept together and there is actually no such thing as a GTE flow time. This produces an unusual scheduling situation for GTEs. As shown on Figure 8.1-2, the front half of the process, (from induction to the parts pool), is managed on a Just In Case (JIC) schedule while the back half, (parts pool to final sell) is managed Just In Time (JIT). The existence of the parts pool, serving as an enormous inventory buffer, allows these two scheduling programs to exist in the same process.

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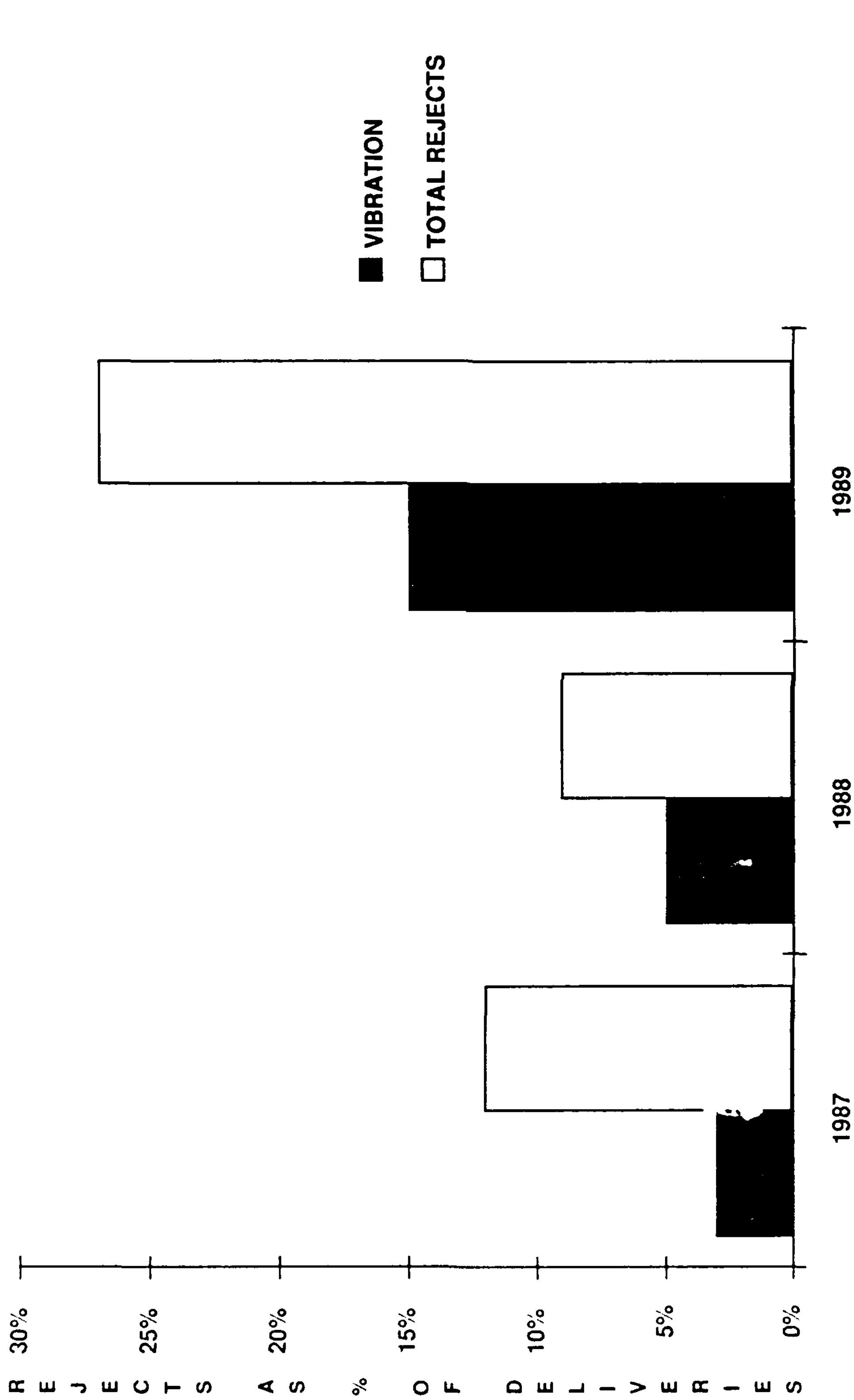

-180 GTE VIBRATION REJECTS
FIGURE 8.1.2.2-1

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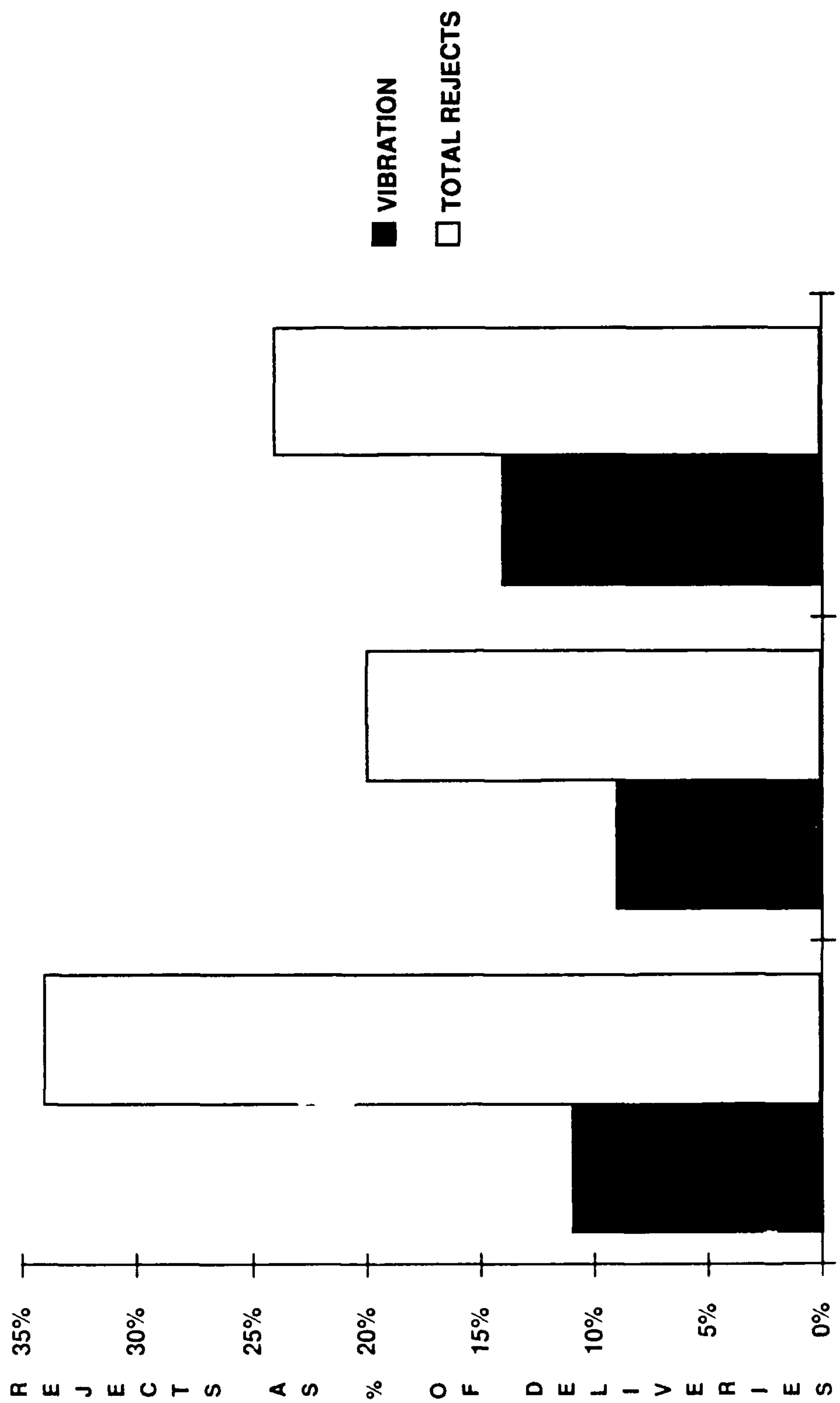
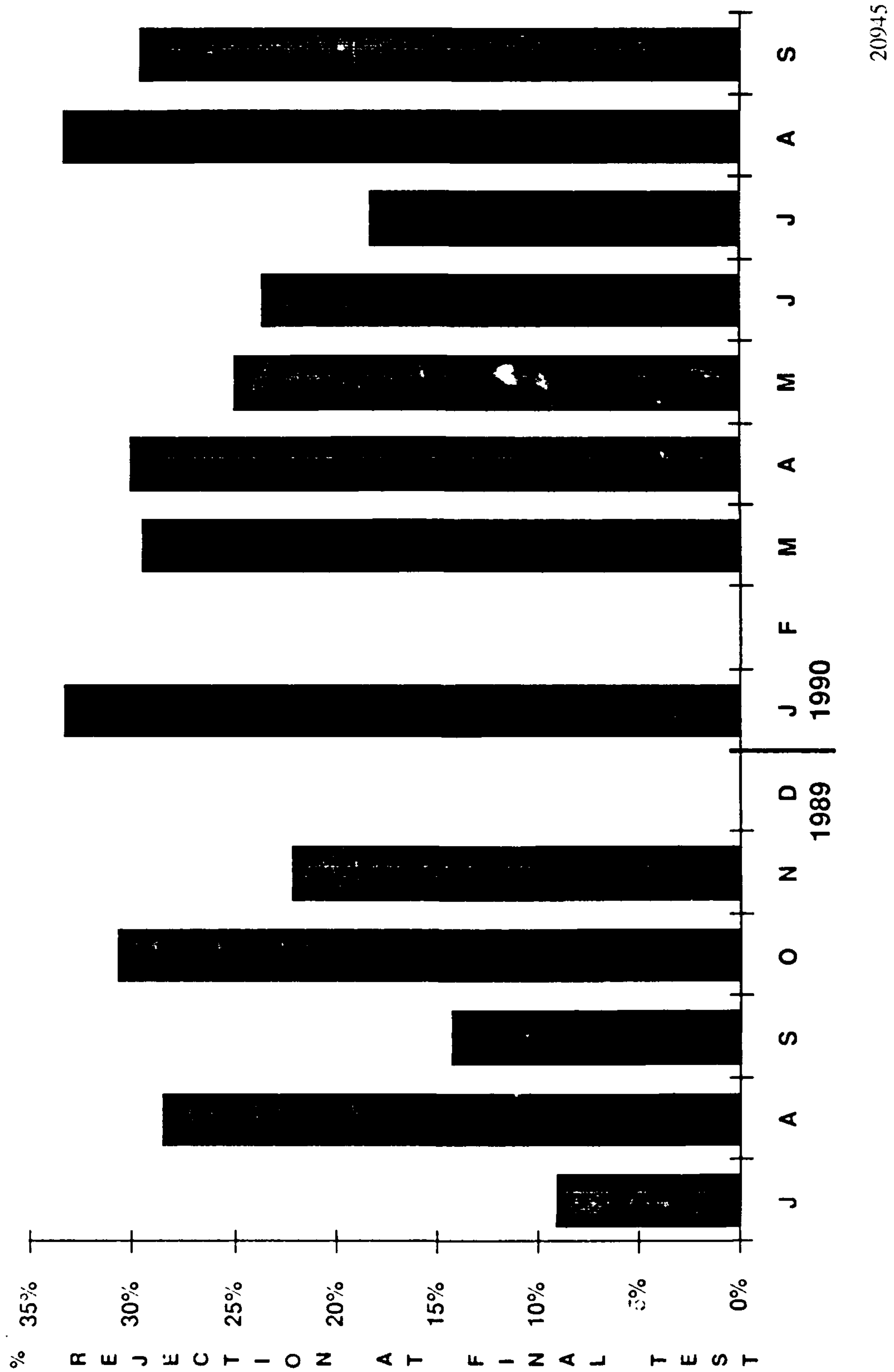
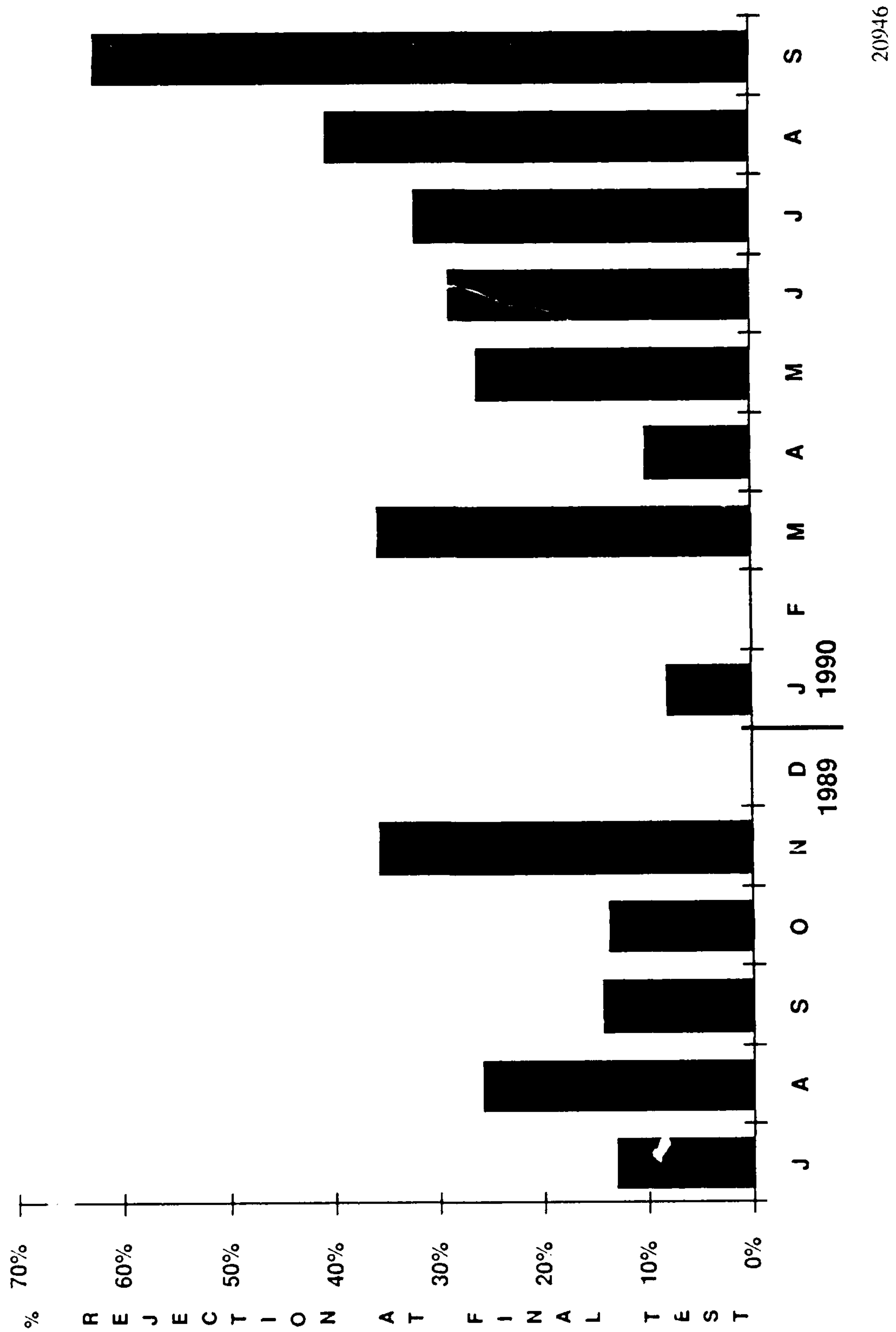


-397 GTE VIBRATION REJECTS
FIGURE 8.1.2.2-2



-180 GTE 12 MONTH REJECT HISTORY AT FINAL TEST
FIGURE 8.1.2.2-3



-397 GTE 12 MONTH REJECT HISTORY AT FINAL TEST

FIGURE 8.1.2.2-4

In the front half of the GTE process, GTEs are inducted, disassembled, and routed through the Inspect/repair processes based largely on induction capacity, rather than demand. Parts are "pushed" into the process on the assumption that something will eventually arrive at the other end. Once likened to a sausage-stuffing machine, this system produces very long flow times (over 90% of the total engine flow times in the UDOS model) and extremely high Work In Process (WIP) inventories. None of the GTEs or subassemblies in this portion of the process are scheduled in any way.

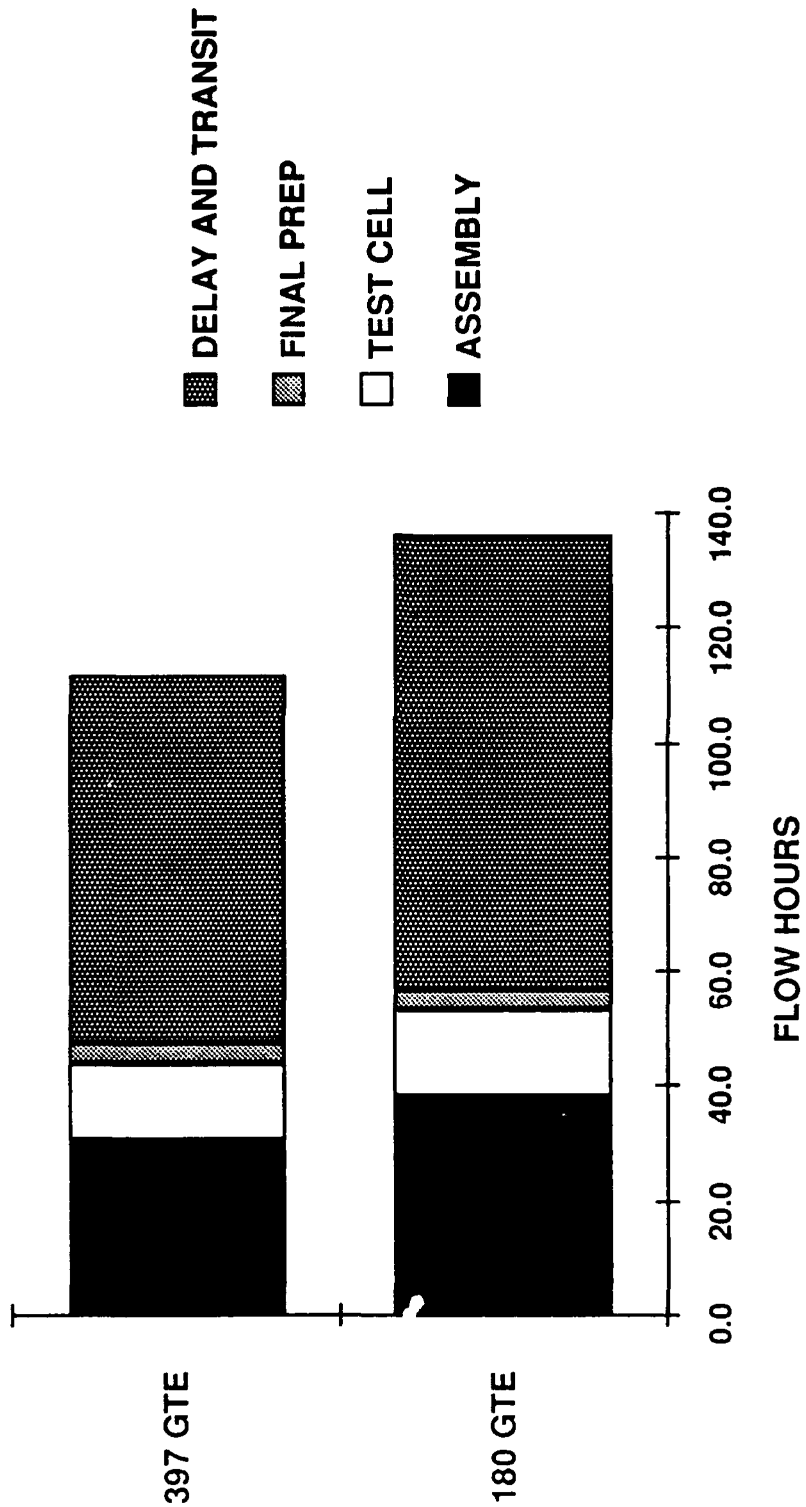
In the back half of the process, GTE kits are "pulled" from the parts pool on a JIT schedule. The monthly delivery schedule for GTEs identifies how many of each GTE kit are required. Those kits are built up and delivered to assembly as required. Assembly builds GTEs from the kits and sends them to final test and then (for those which pass) to final sell. The average flow time for both GTEs studied is 15 days from kit issue to final sell. Figure 8.1.2.3-1 shows the actual distribution of these flow times. WIP levels are extremely low (seldom more than current production requirements) and everything is driven by the delivery schedule.

MDMSC recommends that the efficient JIT system be used throughout the GTE process. To do so would require an enhanced scheduling system and the elimination of the parts pool. A computerized scheduling system is planned for the area, as described in Paragraph 8.1.3 of this report. MDMSC recommends, in the interim, that the scheduling and process flow described in Paragraph 8.3.1.1 of this report be adopted by SA-ALC.

8.1.2.4 Obsolete Design of Current GTEs

The original GTE design, on which both the -180 and -397 GTEs are based, was developed in the 1950s. Since that time, numerous modifications have been made to increase flow pressures but no significant redesign of the engine(s) have taken place.

The current four-bearing design is extremely sensitive to minor variations in parts dimensions and is difficult and expensive to maintain. The commercial airlines surveyed in this study have universally abandoned four-bearing designs in favor of



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GTE AVERAGE FLOW FROM KITTING TO FINAL SALE
FIGURE 8.1.2.3-1

more modern (and reliable/maintainable) designs. Garrett APD reports that they are still in production of a version of the -180 but have discontinued all production on the -397s.

MDMSC recommends the Air Force give serious consideration to replacing the current -180 and -397 GTEs with newer engines.

8.1.3 Future Plans

This paragraph describes the SA-ALC future plans for GTE repair which have been briefed to MDMSC engineers. It includes MDMSC's evaluations and recommendations regarding the plans.

Water-Jet Blasting - The PRAM-funded project involves the purchase of a robotic water blast cleaning system to remove seals and gaskets from engine fan cases. The new equipment is intended to replace manual scraping, grit blasting, and chemical stripping, with a robotic water blasting process. MDMSC concurs that the water blast system will remove seals and gaskets, but questions the applicability of a robotic design. MDMSC recommends a CO_2 blast process be acquired rather than a water blast process, and the abandonment of a robotic element to the design. The PRAM funding document projects cleaning times with water blast to be 25 minutes (versus 2 1/2 hours manually) and specifies the use of a booth for worker safety. An MDMSC sponsored test of the CO_2 blast process removed gaskets from a fan case in seconds (video tapes and photographs of the test were provided to SA-ALC engineers on Task Order No. 14), without requiring a protective booth. The CO_2 blast process is cheaper ($160,000 vs an estimated $280,000 for the water blaster) and produces no hazardous waste. Operating costs are estimated to be roughly equal between the two options.

New Cleaning Line - MATPSI is in the process of installing a new chemical cleaning line for GTE parts. MDMSC predicts that the line, when functioning, will clean GTE parts in one to two days where the current cleaning process in Building 360 requires nine to ten days. MDMSC does not believe, however, that the new line will actually clean parts more effectively than the Building 360 process. Given current environmental restrictions, chemical dipping is largely obsolete as a cleaning/paint stripping process. The chemical cleaning processes generate large volumes of toxic

waste, without fully cleaning anything. 94% of the parts dipped in the Building 360 lines require additional manual cleaning/blasting before they can be inspected. MDMSC projects similar results for the GTE cleaning line.

MDMSC recommends that the GTE community consider a CO_2 blasting system similar to that recommended in the Task Order No. 14 CSR. This system will clean parts and strip paint without vapor degreasing and generates no hazardous waste.

Multi-Station Blending and Deburring Station - This system involves the installation of blending/deburring capability at each APIS dimensional inspection station. While MDMSC has no information regarding the design of this system or its cost, the concept is excellent. The APIS inspection operation is a process bottleneck. Anything which can improve the productivity or quality at this operation will have positive effects on the entire GTE production process.

Automated FPI Process - This plan involves the development of an Automated FPI system, similar to the Integrated Blade Inspection System (IBIS) in Building 360, for use on GTE workloads. MDMSC does not believe that this project, as described, will be cost effective. The IBIS system was designed to inspect engine blades - an extremely high-volume (93,000/month) workload with relatively low part-geometry variation, but is only useful for roughly 5% of the blade workload. A workload such as that found in MATPSI (Low volume - highly variable geometry) is the worst possible candidate for robotic technologies. MDMSC estimates that software development costs for such a system will be over $15 million (SA-ALC estimated costs for the project is $1.5 million), while hardware will run $1 - 3 million. MDMSC engineers are unaware of any off-the-shelf system which remotely approximates the desired capabilities of this system.

Rather than implement the system described, the MDMSC FPI specialist recommends replacing the current level 3 hydrophilic penetrant with a water washable solution at level 4 sensitivity. This would allow the penetrant to be removed with a water spray, rather than the present hydrophilic remover, and eliminate one rinse step. This would reduce the worker's exposure to the penetrant and decrease FPI flow time roughly 10%.

Automated Scheduling System - This plan involves the development of a multi-station computer scheduling/tracking system for GTE production. Its goal is to increase throughput/reduce flow time by improved scheduling. MDMSC recommends this system be implemented as soon as possible. As indicated by data in the UDOS 2.0 model, GTE flow times are extremely long and WIP inventories very high. This is a function of poor (actually a complete lack of) scheduling, not insufficient resources. In MDMSC's study of commercial aircraft maintenance centers, it was obvious that the major difference between good centers (Delta, Southwest Airlines, United) and excellent ones (American, Northwest Airlines, AAR) was an ability to schedule. All the best centers have powerful computerized multi-station scheduling tools, while the others are all in the process of developing, purchasing, or upgrading their own systems.

8.2 SIMULATION MODEL

A simulation model was constructed by MDMSC engineers under the supervision of an on-site simulation specialist, using the UDOS 2.0 model. This simulation modeled the entire process flow of two selected GTEs (the -180 and -397 engines) through their entire repair process, from induction through final sell. This process flow included the individual flows of 15 critical subassemblies (selected by the SA-ALC engineer assigned to Task Order No. 15) across seven separate RCCs. By following two end items across the entire process, the problems of "sub-optimalization" (increasing the efficiency of a portion of the process but not significantly affecting the whole) found in some individual RCC models were avoided. MDMSC commends the SA-ALC engineers for specifying this modeling process and recommends it become the IPI process characterization method of choice on future Task Orders.

The flow times of various parts through the repair RCCs were modeled using historical data collected from PAC-stamped WCDs. MDMSC collected and key punched the flow times shown on representative samples of WCDs completed in FY 90. Histograms were prepared from this data and used to develop average flow times and their probabalistic distributions for use in the UDOS model. This flow data was reviewed by SA-ALC engineers prior to use and is considered the most accurate flow data available. It is reported by GTE and subassembly, across each RCC and primary operation in Paragraph 8.1 of this report. The details of this data can be found in Section 8.2 of the DDB.

While historical flow time data was available between RCCs, it was not available for individual operations within RCCs nor for the actual process times (touch times) required for each operation. This data was obtained from the validated UDOS files generated under Task Order No. 1, updated as required with data collected from shop floor interviews. In back shops, at SA-ALC engineering request, MDMSC used current SA-ALC labor standards (from the GO19C report) to model process times. This data is displayed in Paragraph 8.1 of this report, and in Section 8.2 of the DDB.

The UDOS 2.0 model was validated in accordance with the Acceptance Test Procedure (ATP) called out in MDMSC's proposal. As required by the ATP, model outputs were compared to historical data collected on the GTE repair process. All simulated flow times were within 15% of the historical average and all simulated

throughput figures were within 10% of historical performance. Details of the validation procedure can be found in Section 8.2 of the DDB and the validation report submitted by MDMSC as CDRL item 15A017. The final phase of validation was witnessed by the IPI working group member (acting) at SA-ALC.

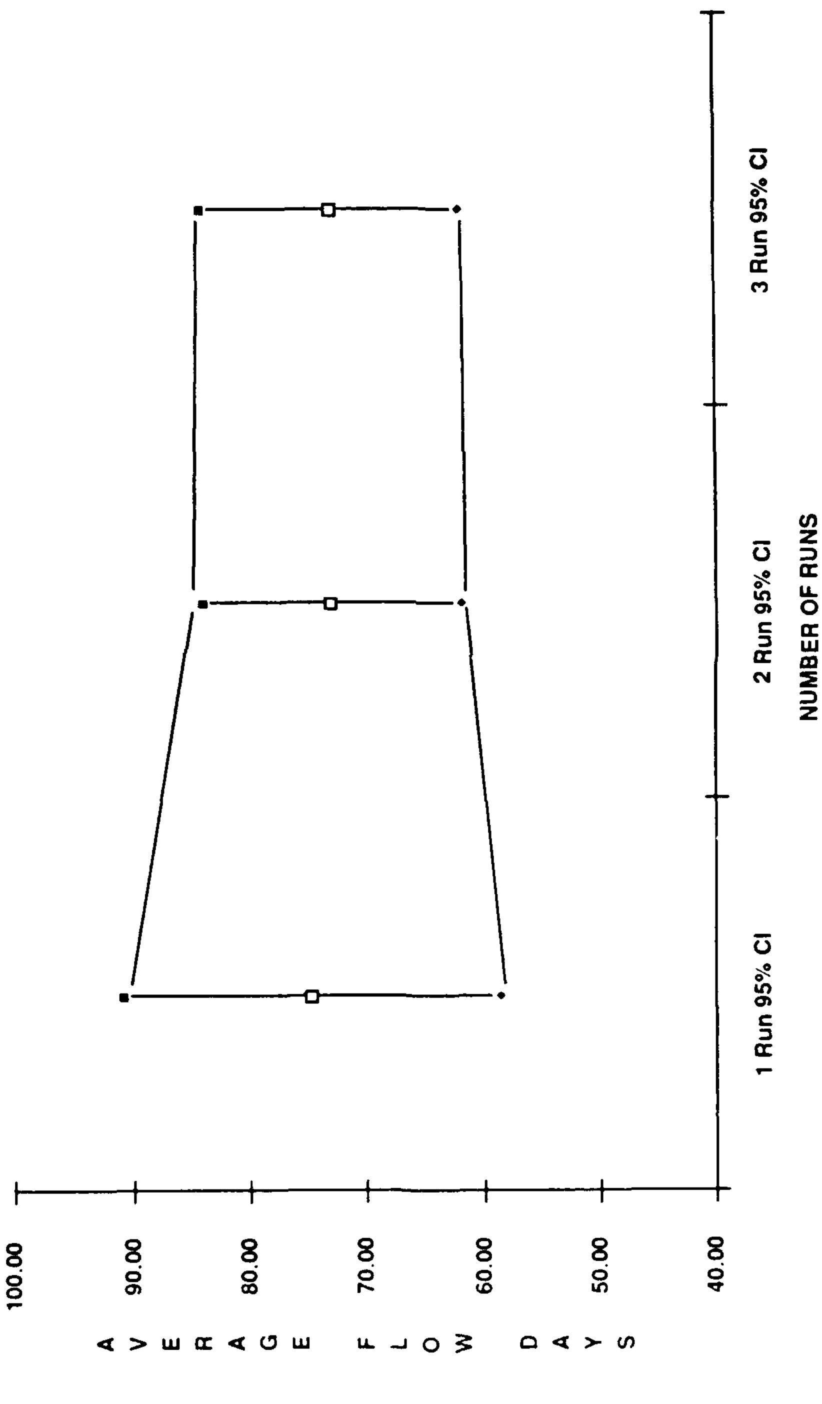
The validated model was run at three random seeds. At a 95% confidence interval the flow time variance attributable to random seed changes decreased insignificantly between two seed runs and three. This led MDMSC to decide to use two random seed runs for each model experiment. Figure 8.2-1 shows this graphically. More detail can be found in Section 8.2 of the DDB.

8.2.1 Additional Data Collection

At the request of SA-ALC engineers, MDMSC began a parts tagging program to provide additional data on the flow of GTE parts through the SA-ALC repair process. While not required by the Task Order No. 15 contract, MDMSC volunteered to perform this task in an attempt to increase SA-ALC satisfaction with the task order performance.

The program itself involved tagging critical parts, using blue cardboard "Traveler" tags prepared by MDMSC. Figure 8.2.1-1 shows one of these tags. The tags were placed on critical subassemblies of the -180 and -397 GTEs, at various points in the repair process. Material handling workers in both MAT and MAE were briefed on the program and requested to log the dates and times parts were moved between RCCs/operations. This data was collected to evaluate GTE flow times. Production supervisors in each RCC affected were provided with logbooks and asked to log the production time spent repairing each tagged item. This data was collected to evaluate GTE processing times.

This program was operated for roughly three months by MDMSC engineers (devoting an estimated 400 manhours to the effort). During this time 800 parts were tagged and 183 tags were collected at the designated collection points. Given the relatively short duration of the study and the long flow times for GTEs (four to five months), the program failed to yield a detailed picture of the flow of GTEs. It did, however, yield data on certain points in the process (showing for example, that the actual average flow time for a basket of GTE parts through the Building 360 cleaning line is currently



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GTE - 3 RUN 95% CONFIDENCE INTERVAL
FIGURE 8.2-1

Please Log Time and Date Moved **1000**

Part Number________________________________

RCC____________________

In __________________ **Out**__________________

RCC____________________

In __________________ **Out**__________________

RCC____________________

In __________________ **Out**__________________

RCC____________________

In __________________ **Out**__________________

RCC____________________

In __________________ **Out**__________________

RCC____________________

In __________________ **Out**__________________

Industrial Process Improvement Program

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GTE "TRAVELER" TAG
FIGURE 8.2.1-1

running at nine to ten days). The flow data collected by the tagging program showed a strong correlation to data obtained from PAC-stamped WCDs from FY 90. This adds credibility both to the tag data and to the PAC-stamped WCD data used in the UDOS simulation model.

Several problems were encountered in the conduct of this program, which account for much of the variability in the data collected:

- Both material handling and production personnel frequently failed to document data on the tags or production logs. This produced gaps in the documentation and reduced the effective sample size.
- Material handling and production personnel occasionally misunderstood the purpose of the tag and assumed it indicated a "hot" part. As a result, some of the tagged parts were expedited, causing their flow data to be abnormally short.
- Many tags were removed from the parts at unknown points, by persons unknown. This further reduced the available sample size.
- The DESERT SHIELD surge conditions found in the GTE process during this study affected the priority of many parts (tagged and untagged) in the GTE process. This caused unquantified, but possibly significant distortions in the "normal" flow of tagged parts.

MDMSC engineers have provided the SA-ALC engineers with a summary of the data collected during this program, and a report of the current status of the effort. At the end of Task Order No. 15, MDMSC will transfer all existing program functions and data to SA-ALC engineering, along with an additional supply of tags, should SA-ALC elect to continue the program using government personnel.

MDMSC recommends that this study be continued by SA-ALC engineers. The effort was/is very labor intensive, however, and would benefit by a more automated methodology. MDMSC's recommendation for the purchase of a radio tracking system is described in Paragraph 8.3.3.1 of this report

8.2.1.1 Brainstorming

During the construction of the UDOS model, several brainstorming sessions were conducted among MDMSC and SA-ALC engineers to determine what experiments

should be conducted using the model. The final set of experimental factors and levels selected is listed in Table 8.2.1.1-1.

After examining the list and the validated GTE model, MDMSC prepared a recommended experimental design. This design was discussed with SA-ALC engineers and accepted without change. The details of this design are described in the next paragraph.

8.2.1.1.1 Design

Because of the large number of experimental factors involved, and their varying potential for interaction, MDMSC developed a double-array experimental design. In this design, factors are fitted into an inner (L_4) or an outer (L_9) Taguchi orthogonal array. While the experiments are fractionally factorial within each array, the relationship between the arrays is fully factorial. This allows interactions between the arrays to be fully described. The experimental design is shown in Figure 8.2.1.1.1-1.

This design is one recommended by Dr. Taguchi when multiple noise factors are tested against multiple control factors. The inner array contains those factors determined to be controls while the outer contains the noise factors. As the relationship between the two arrays is fully factorial, the designation of "INNER" and "OUTER" is a matter of design protocol (selected by Dr. Taguchi) rather than a statistical decision.

MDMSC estimates were used to model the expected flow time for bearing housing operations moved to Bldg 329. All other factors and levels were derived as percentage changes over the values in the validated UDOS model. All reject data in the model was developed from actual historical data found in the Final Test cell logs and automated data collected from the test cell computers.

8.2.1.1.2 Conduct of Experiments

All experimental runs were conducted by MDMSC in accordance with the SOW and Task Order No. 15 proposal. The experiments in the L_4 and L_9 arrays were run using two different random number seeds and the results averaged, for a total of 72 individual model runs.

GTE EXPERIMENTAL FACTORS
TABLE 8.2.1.1-1

L_9

FACTORS	LEVELS 1	LEVELS 2	LEVELS 3
1. MANPOWEF	AS-IS	DECREASED BY 10%	DECREASED BY 20%
2. WORKLOAD	AS-IS	INCREASED BY 50%	INCREASED BY 100%
3. REJECT RATE (AT FINAL TEST)	AS-IS (24%)	DECREASED BY 50% (TO 12%)	DECREASED BY 100% (TO 0)
4. FLOATING STOCK (WORK IN PROCESS)	AS-IS	FLOATING STOCK SET AT 10% OF AVERAGE WIP	FLOATING STOCK SET AT 30% OF AVERAGE WIP

L_4

FACTORS	LEVELS 1	LEVELS 2
1. MOVE THE BEARING HOUSING WORKLOAD IN-HOUSE	AS-IS (BLDG. 303)	MOVED TO BLDG. 329
2. INDUCTION SCHEDULE	AS-IS (RANDOMLY THROUGHOUT THE MONTH)	INDUCT ALL GTEs AT THE BEGINNING OF EACH MONTH
3. 1 X 2 INTERACTION	1	2

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L_9 OUTER ARRAY

EXP	MANPOWER	WORKLOAD	REJECT RATE	FLOATING STOCK
1	AS-IS	AS-IS	AS-IS	AS-IS
2	AS-IS	+50%	-50%	+10%
3	AS-IS	+100%	-100%	+30%
4	-10%	AS-IS	-50%	+30%
5	-10%	+50%	-100%	AS-IS
6	-10%	+100%	AS-IS	+10%
7	-20%	AS-IS	-100%	+10%
8	-20%	+50%	AS-IS	+30%
9	-20%	+100%	-50%	AS-IS

X

L_4 INNER ARRAY

EXP	BEARING HSG	INDUCTIONS	1 X 2
1	AS-IS	AS-IS	1
2	AS-IS	MONTHLY	2
3	BLDG 329	AS-IS	2
4	BDLG 329	MONTHLY	1

NOTE: (1) EACH EXPERIMENT IN THE OUTER ARRAY IS REPEATED FOR EACH EXPERIMENT IN THE INNER ARRAY. THE RELATIONSHIP IS FULLY FACTORIAL.
4 INNER ARRAY EXPERIMENTS X 9 OUTER ARRAY = 36 EXPERIMENTS. EACH EXPERIMENT WAS REPEATED AT 2 RANDOM SEEDS FOR A TOTAL OF 72 UDOS MODEL RUNS.

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GTE EXPERIMENTAL DESIGN

FIGURE 8.2.1.1.1-1

8.2.1.2 Experimentation

Experimentation was conducted by MDMSC using the validated GTE process simulation model, in accordance with the Task Order No. 15 SOW and proposal. Actual model runs were made on MDMSC computers, with SA-ALC computers used on a space-available basis.

8.2.1.3 Analysis

This paragraph describes the results of the UDOS 2.0 model experiments conducted by MDMSC for the GTE repair community, under Task Order No. 15.

8.2.1.3.1 Taguchi Analysis

The results of the Taguchi experiments are displayed graphically in Section 8.2.1.3.1 of the DDB.

An analysis of these results was performed using the methodology developed by Dr. Genichi Taguchi, as specified in the IPI general SOW. The detailed results of this analysis are included in Section 8.2.1.3.1 of the DDB. Summaries of the results for Flow Time, Throughput, and WIP are shown in Figures 8.2.1.3.1-1 through 8.2.1.3.1-3.

Using a "smaller is better" analysis, the predicted optimal configuration of noise and control factors is shown in Table 8.2.1.3.1-1. As shown in the table, the results of the confirmation runs were both within 10% of the results predicted by the Taguchi methodology. MDMSC concludes that the predicted results of the Taguchi optimal configuration have been confirmed and that the experiments conducted are valid.

Table 8.2.1.3.1-2 shows the Signal to Noise Ratios (S/N) for each experiment in the L_4 (Control Factor) arrays. As there is no significant variance among the runs, MDMSC concludes that the control factors selected do not contribute to the robustness (sensitivity to noise) of the GTE process at the noise factors selected.

CONTROL (L_4)

	FACTORS	LEVELS	
-180		BLDG 303	BLDG 329
	BEARING HSG	138	129
		AS-IS	MONTHLY
	INDUCTION SCH.	132	136
		1	2
	INTERACTION 1X2	N/A	N/A
-397		BLDG 303	BLDG 329
	BEARING HSG	149	149
		AS-IS	MONTHLY
	INDUCTION SCH.	147	151
		1	2
	INTERACTION 1X2	N/A	N/A

NOISE (L_9)

	FACTORS	LEVELS		
-180		AS-IS	-10%	-20%
	MANPOWER	125	125	151
		AS-IS	+50%	+100%
	WORKLOAD	107	113	181
		AS-IS	+12%	+0%
	REJECT RATE	136	142	122
		AS-IS	+10%	+30%
	FLOATING STOCK	153	131	116
-397		AS-IS	-10%	-20%
	MANPOWER	144	142	161
		AS-IS	+50%	+100%
	WORKLOAD	128	137	182
		AS-IS	+12%	+0%
	REJECT RATE	150	156	141
		AS-IS	+10%	+30%
	FLOATING STOCK	173	148	126

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GTE FLOW TIME RESULTS
FIGURE 8.2.1.3.1-1

CONTROL (L_4)

	FACTORS	LEVELS	
-180		BLDG 303	BLDG 329
	BEARING HSG	100%	86%
		AS-IS	MONTHLY
	INDUCTION SCH.	87%	87%
		1	2
	INTERACTION 1X2	N/A	N/A
-397		BLDG 303	BLDG 329
	BEARING HSG	100%	89%
		AS-IS	MONTHLY
	INDUCTION SCH.	89%	88%
		1	2
	INTERACTION 1X2	N/A	N/A

NOISE (L_9)

	FACTORS	LEVELS		
-180		AS-IS	-10%	-20%
	MANPOWER	92%	88%	80%
		AS-IS	+50%	+100%
	WORKLOAD	100%	96%	73%
		AS-IS	+12%	+0%
	REJECT RATE	82%	85%	90%
		AS-IS	+10%	+30%
	FLOATING STOCK	85%	88%	87%
-397		AS-IS	-10%	-20%
	MANPOWER	93%	91%	82%
		AS-IS	+50%	+100%
	WORKLOAD	100%	98%	75%
		AS-IS	+12%	+0%
	REJECT RATE	83%	84%	90%
		AS-IS	+10%	+30%
	FLOATING STOCK	84%	91%	92%

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GTE THROUGHPUT RESULTS
FIGURE 8.2.1.3.1-2

-180

CONTROL (L_4)

FACTORS	LEVELS	
	BLDG 303	BLDG 329
BEARING HSG	43	41
	AS-IS	MONTHLY
INDUCTION SCH.	41	43
	1	2
INTERACTION 1X2	N/A	N/A

NOISE (L_9)

FACTORS	LEVELS		
	AS-IS	-10%	-20%
MANPOWER	38	40	49
	AS-IS	+50%	+100%
WORKLOAD	21	34	72
	AS-IS	+12%	+0%
REJECT RATE	42	47	37
	AS-IS	+10%	+30%
FLOATING STOCK	49	41	36

-397

CONTROL (L_4)

FACTORS	LEVELS	
	BLDG 303	BLDG 329
BEARING HSG	85	85
	AS-IS	MONTHLY
INDUCTION SCH.	84	86
	1	2
INTERACTION 1X2	N/A	N/A

NOISE (L_9)

FACTORS	LEVELS		
	AS-IS	-10%	-20%
MANPOWER	79	82	94
	AS-IS	+50%	+100%
WORKLOAD	47	75	133
	AS-IS	+12%	+0%
REJECT RATE	84	93	78
	AS-IS	+10%	+30%
FLOATING STOCK	99	84	72

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GTE WIP RESULTS (IN GTEs)
FIGURE 8.2.1.3.1-3

GTE TAGUCHI EXPERIMENTATION CONFIRMATION RUN RESULTS

TABLE 8.2.1.3.1-1

	L_4					L_9			PREDICTED FLOW TIME RESULTS			CONFIRMATION RUN RESULTS FLOW TIME	Δ	$\%\Delta$
	BEARING HSG LOCATION	INDUCTION SCHEDULE	INTERACTION 1X2		MANPOWER	WORKLOAD	REJECT RATE	FLOATING STOCK	L_4	L_9	WEIGHTED AVERAGE[1]			
-180	AS-IS	AS-IS	N/A		AS-IS	AS-IS	0%	+30%	3040 HOURS	1666 HOURS	2089 HOURS	1890 HOURS	199 HOURS	10%
-397	B329	AS-IS	N/A		-10%	AS-IS	0%	+30%	3522 HOURS	2177 HOURS	2590 HOURS	2400 HOURS	190 HOURS	7%

(1) WEIGHTED BY NUMBER OF EXPERIMENTAL RUNS IN EACH ARRAY.

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SIGNAL TO NOISE RATIOS - GTE TAGUCHI EXPERIMENTATION
TABLE 8.2.1.3.1-2

	-180 GTE		-397 GTE	
EXP	S/N RATIO FLOW TIME	S/N RATIO WIP	S/N RATIO FLOW TIME	S/N RATIO WIP
1	70.6 db	-33.7 db	-71.2 db	-39.3 db
2	-70.9 db	-33.9 db	-71.4 db	-39.6 db
3	-70.1 db	-33.3 db	-71.1 db	-39.2 db
4	-70.4 db	-33.6 db	-71.4 db	-39.5 db
RANGE(1)	.8 db	.6 db	.3 db	.4 db

(1) No experimental factor produced a change in S/N greater than .8 db

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The following sections describe the effects of each experimental factor, and offer MDMSC's recommendations regarding their interpretation.

CONTROL FACTOR 1 - Moving bearing housing repair to Building 329. MDMSC recommends that the -180 bearing housing repair work be brought in-house in the GTE process and performed in Building 329. In the simulation experiments, this change produced an average 7% (nine day) reduction in the flow time of -180 GTEs. The bearing housing is currently a critical path item for the -180 GTE. By bringing the bearing housing workload in-house the critical path shifted, limiting the overall affect of the change on the -180 flow time. This experiment supports MDMSC's recommendation for all machining work to be brought in-house. Paragraph 8.3.2 describes this in more detail. This change showed no interaction with CONTROL FACTOR 2.

CONTROL FACTOR 2 - Inducting all GTEs at the beginning of each month. MDMSC does not recommend that GTEs be inducted in batches at the beginning of each month. This change caused an average 3% (four day) increase in the flow times of both the -180 and -397 engines. This was caused by an effective increase in the GTE batch size when inductions were grouped at the first of the month. As predicted in the book THE RACE, the increased batch size caused lengthened flow times and increased inventory levels. In reality, given the JIC flow found in the front half of the GTE overhaul process (see paragraph 8.1.2.2 for details), this change would not affect the current process on the shop floor. This experiment does, however, predict the affects expected under the MDMSC recommended process flow as described in Paragraph 8.3.1.1.

This change showed no interaction with CONTROL FACTOR 1.

NOISE FACTOR 1 - Reducing manpower. MDMSC recommends that 10% of the personnel currently assigned to disassembly be re-trained and re-assigned to Inspection. A 10% reduction in available manpower produced no change in - 180 flow times and an insignificant improvement (less than one day) in -397 flow times. The cause of this appears to be that a 10% reduction in personnel at the front end of the process reduced the rate at which GTEs could be inducted. This, in turn, reduced the effective batch size of GTEs in-work and offset the downstream effects of reduced

manpower. The effect was swamped by the overall reduction in production capacity when manpower was reduced by 20% - causing an average 25 day increase in the flow times of both engines. As with the change in induction schedules, this effect would only be observed under a JIT flow as recommended by MDMSC in Paragraph 8.3.1.1 of this report. Neither CONTROL FACTOR showed any interaction with this NOISE FACTOR.

NOISE FACTOR 2 - Increasing workload. <u>MDMSC recommends that current workload levels not be increased by more than 50% without the addition of additional inspection personnel</u>. A 50% increase in the -180 and -397 GTE workloads produced only a four day increase in average -180 flow times and a nine day increase for the -397. A 100% increase (doubling) however, caused flow times to increase by 60 and 80 days respectively. <u>The critical resource causing this process bottleneck is the MATPSI inspections personnel</u>. Neither CONTROL FACTOR showed any interaction with this NOISE FACTOR.

NOISE FACTOR 3 - Reduction of Rejection Rates at final test. <u>MDMSC recommends that every effort be made to reduce the rate of rejection at final test</u>. By eliminating the rejects at final test (currently modeled at 24% in the baseline validated model), the flow time for the -180 GTEs was reduced by 12 days while the flow time for -397s dropped almost 18 days. This was the second most significant improvement produced by any factor included in the experimental design. In addition to the flow time improvements, throughput rose an average 5% and WIP levels fell 5 units for the -180 and six units for the -397. At current costs, this WIP inventory reduction has a value of $818,738. Further details regarding MDMSC's recommendations regarding reject rates and their reduction can be found in Paragraphs 8.1.2.1 and 8.3.1.2 of this report. Neither CONTROL FACTOR showed any interaction with this NOISE FACTOR.

NOISE FACTOR 4 - Increase in floating stock levels. The increase of floating stock levels to 10% and 30% produced an average 25 day and 19 day drop respectively in the flow times of both engines. This occurred because the increased availability of parts at assembly allowed more GTEs to be assembled without waiting on the repair of inducted subassemblies. In reality, the parts pool represents an enormous supply of floating stock (through of undetermined quality/serviceability), maintained at an unknown cost. Simply increasing the levels of floating stock in the GTE process

(already enormous) would not be cost effective. MDMSC does not recommend an increase in inventory without more process analysis. Neither CONTROL FACTOR showed any interaction with this NOISE FACTOR.

8.3 CONCLUSIONS

8.3.1 Focus Studies

This paragraph describes MDMSC process improvement recommendations which require additional study, or which would require over six months or $200,000 in capital investment to implement.

8.3.1.1 Development of a JIT Flow in the GTE Process

This paragraph describes an improved flow of GTEs based on JIT principles. The recommended flow is designed to minimize flow time and inventory for the affected GTEs while facilitating the development of statistical process control.

8.3.1.1.1 Rationale Leading to Change

As described in Paragraph 8.1, the current GTE flow is primarily a JIC system, but flows JIT from the parts pool to final sell. This recommendation describes an MDMSC - developed plan to convert the entire process flow for the -180 and -397 GTEs to a JIT system.

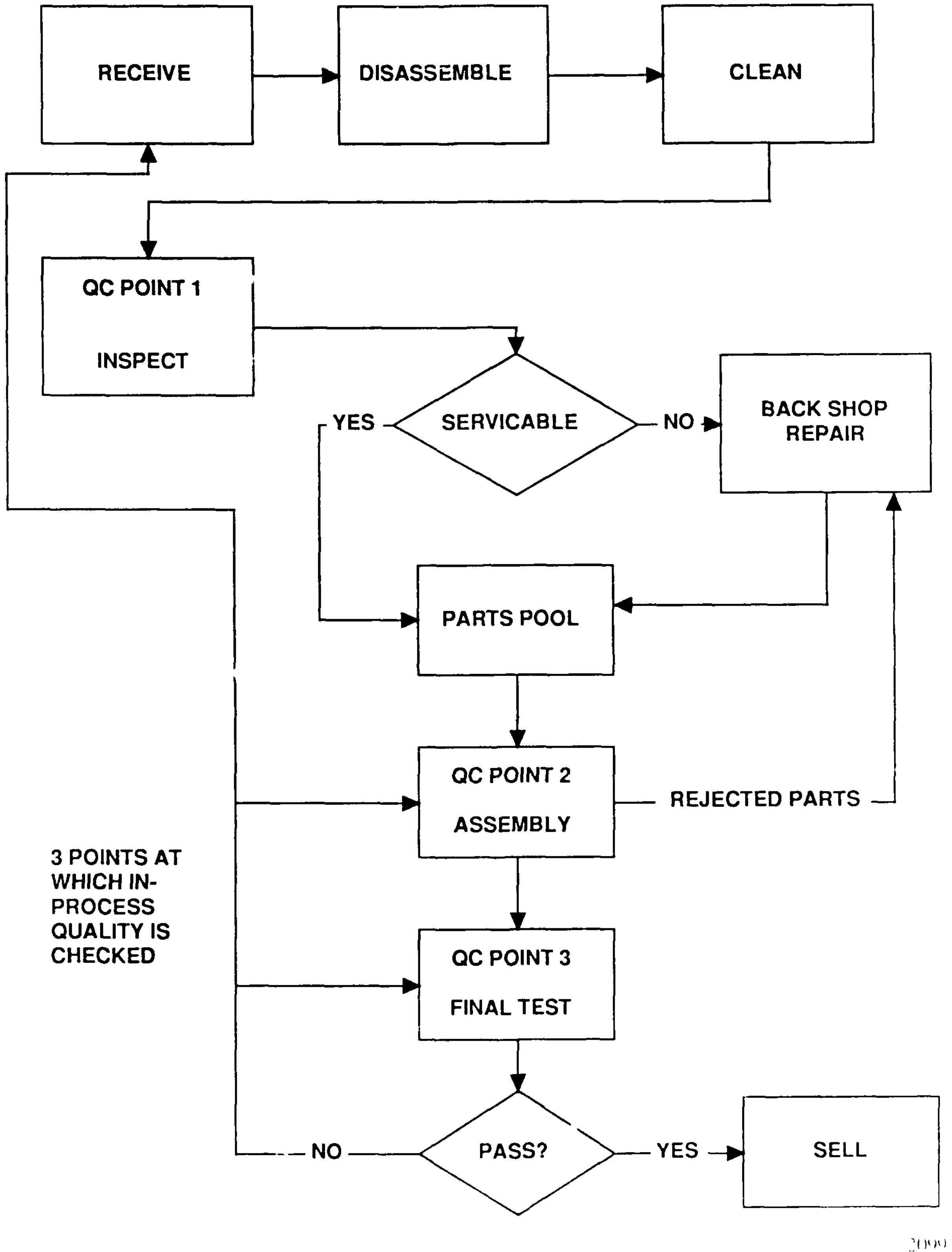
The current system produces extremely high WIP inventories and extremely long flow times. While no accurate count of GTE inventory in SA-ALC was available for this study, MM item manager figures show the current WIP inventory levels at 203 for the -180 and 323 for the -397. This WIP inventory, at the USAF replacement costs of $76,000 for the -180 and $73,123 for the -397, has a value of $39 million. This extremely expensive build-up of WIP inventory is a direct function of the current JIC flow.

Currently, induction/disassembly and assembly/final sell operate from two different schedules. The parts pool, in Building 329 acts as the buffer between these mismatched schedules, and is the storage point for the bulk of the WIP inventory. After being repaired, parts are sent to the parts pool, where they wait for an indeterminate length of time, in an unknown condition. This situation not only encourages the build-up of inventories, but leaves the GTE process vulnerable to significant quality problems.

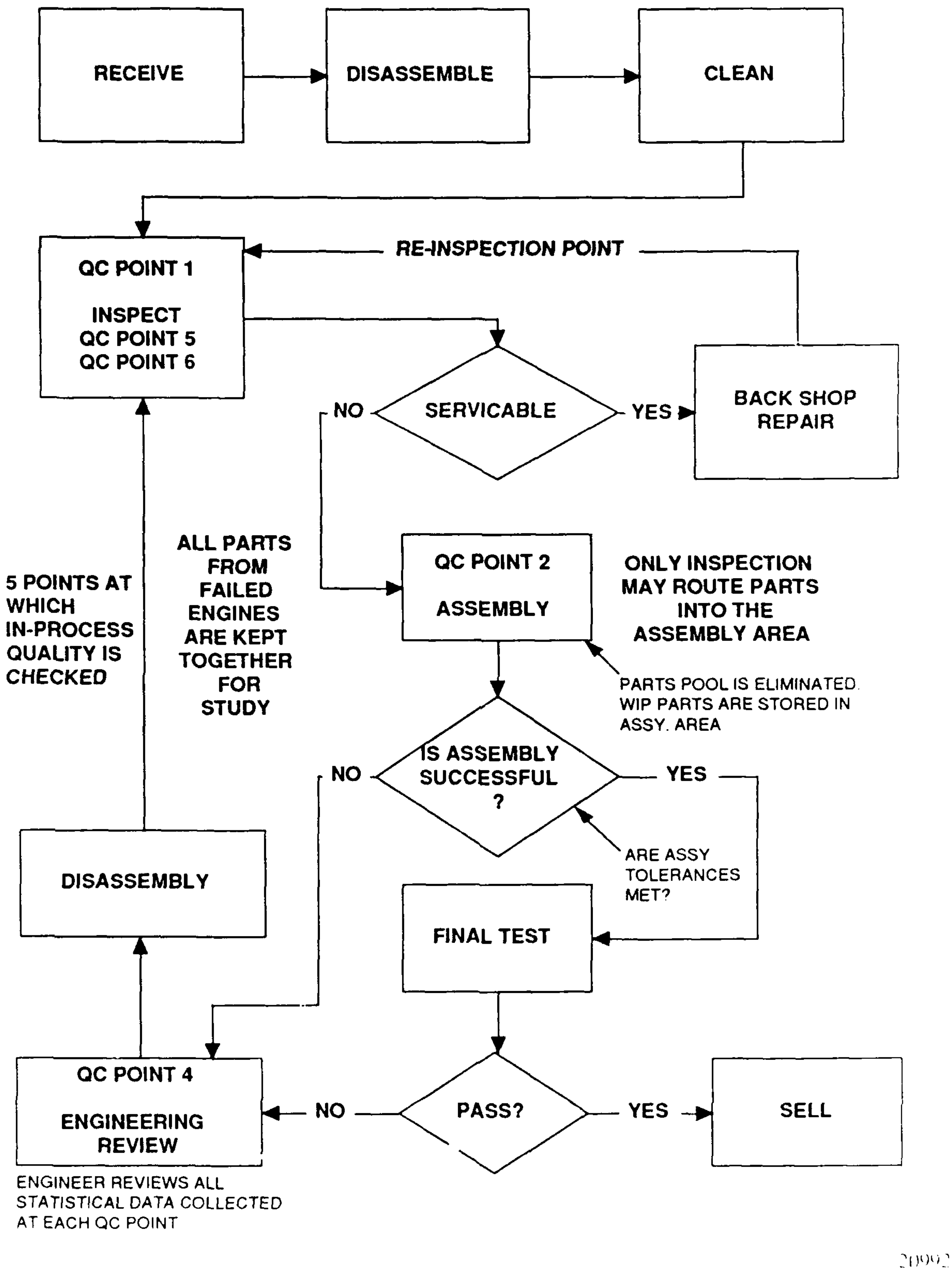
As parts can remain, uninspected, in the parts pool for months, any process quality problems in the repair processes will go undetected for those same months. When problems are detected (by a rejection at final assembly), the feedback to the repair craftsmen (who are responsible for tracking their own process quality) is severely delayed. This situation renders the PAC program useless (in the GTE areas affected) and insures that any process problems will normally delay the production of GTEs. A similar system (using an enormously expensive overhead conveyor/stacker system similar to that found in Building 360) was in place at the Harley-Davidson plant in the early 1980s. They credit the elimination of that system with much of the improvement they made during their legendary productivity/quality turnaround of 1986. MDMSC believes the GTE process would achieve similar results with the elimination of the parts pool.

Figure 8.3.1.1-1 shows the current flow of GTEs through the repair process, while Figure 8.3.1.1-2 shows the MDMSC recommended flow. The primary differences are the addition of three new process control points (discussed further in the focus study of Paragraph 8.3.1.2) and the elimination of the parts pool. The recommended flow would work as follows:

- The quarterly GTE delivery requirements would be spread evenly across the quarter and would become the induction schedule for the induction/disassembly step. As each GTE is inducted (based on the delivery schedule, not disassembly capacity), Scheduling would tag it with the required due-out date. This date will determine when the GTE must be completed and will allow production managers throughout the process to determine its priority. NO OTHER GTEs WILL BE INDUCTED.
- At disassembly, the craftsmen will tag each disassembled part with a tag showing the serial number of the part, the serial number of the GTE, and the "Due at Assembly" date, which will be 15 days prior to the GTE delivery date. They will all record each part's serial number on a copy of the GTE's Bill of Materials (BOM). This sheet, marked with the individual GTE's serial number and delivery date will be routed to the inspection step with the tagged parts.



CURRENT GTE PROCESS FLOW
FIGURE 8.3.1.1-1



RECOMMENDED GTE PROCESS FLOW
FIGURE 8.3.1.1-2

- Each part will be cleaned and inspected as required. For batched operations, (cleaning, or FPI), where the paper tags must be removed from the parts, numbered metal tags will be attached. The numbers on each metal tag will be written on the paper routing tag, so that the correct paper work can be returned to the correct part.
- At the inspection step, the inspectors will record on the GTE BOM, the destination of any parts routed to a repair operation. The inspectors will then route all parts which do not require inspection, as well as the marked up BOM to the final assembly step. Those parts which require pre-assembly processes (i.e, spin balancing) will be routed as required.
- The final assembly workers will use the BOM as a checklist for building the kit of parts for that GTE. As the scheduled assembly date approaches, production management will know exactly which parts are missing and where they were sent. This will allow Production to manage the flow of parts and give them early visibility of problems.
- As various parts are repaired, they are routed back to Inspection for a re-inspect step prior to being sent to assembly. ONLY INSPECTION MAY SEND PARTS TO ASSEMBLY. This prevents unserviceable parts from being installed on an engine and allows process problems to be identified as soon as possible. <u>Repaired parts must always be inspected ahead of the newly disassembled parts,</u> to keep flows smooth and balanced. This limits the flow at the early stages (initial inspection) and reduces WIP inventories.
- When a repaired part is rejected at inspection, the part is returned to the repair center and GTE production management is immediately notified. The "Due at Assembly" date on the rejected part does not change. This automatically makes it a "hot" part and triggers the repair operation to expedite it. If GTE production decides that the part cannot be repaired in time, they may elect to order a new one or cannibalize from an uninducted GTE. If cannibalization is selected, the donor GTE is <u>not</u> inducted, but stored in the disassembly area until it is scheduled for induction. This is vital in maintaining control of WIP inventories.

This new flow would have quality advantages as well as productivity. Because sets of GTE parts are kept together, the volume of rework currently required to "marry" parts would be eliminated, and fewer out-of-balance/tolerance buildup problems would occur. The new flow, as indicated on Figure 8.3.1.1-2, would also facilitate the

collection of statistical process data and allow a better control of the GTE repair process. The focus study on SPC recommended in Paragraph 8.3.1.2 can only be effectively implemented under a system like this. MDMSC recommends the following actions to implement this focus study recommendation:

- Current WIP figures indicate that there is approximately 2 - 2 1/2 years worth of production of -180 and -397 GTEs in-process in the depot now. All inductions of these engines should be discontinued until the WIP levels fall to approximately 6 months worth of production (Just enough to fill the four to five month worst-case production pipeline, currently modeled in UDOS).
- The induction/disassembly workers freed by stopping inductions should be immediately retrained to work as inspectors. Even after the inductions are resumed, 10% of these workers should remain as inspectors. The UDOS model experimentation described in Paragraph 8.2 of this report indicates that this will be sufficient to allow the inspection operation to keep pace with the rest of the GTE repair process.
- As kits are assembled in the parts pool, they should be routed to Inspection, for a re-inspection prior to being sent to assembly. The inspection process should be operated on two shifts (with the work force evenly divided between them) to improve the flow time through Inspection. Kits should be built up and released from the parts pool at least three weeks prior to the GTE scheduled delivery date. As the parts pool empties, the racks, cages and conveyors should be removed to prevent further WIP storage.
- When the parts pool is unable to locate all the parts required to make up a kit, by the "kit release date" (three weeks prior to scheduled sell), they should release the kit "short" to inspection and immediately inform GTE production management of the situation. GTE management can then attempt to locate the required part(s) in the repair back shops. If this is unsuccessful, a new part should be ordered. If necessary, the part(s) may be cannibalized from an uninducted GTE, to preserve the delivery schedule. A new part must still be ordered, however, (to fill the hole in the donor GTE), and the donor GTE should not be inducted into the depot ahead of schedule.

This program will, in approximately two years; empty the parts pool, reduce the WIP inventory volume by over 50% and reduce the flow time of all affected GTEs proportionately. It does not require any additional manpower, capital investment, or repair process changes. If coupled with the focus study recommendations shown in Paragraph 8.3.1.2 it will produce even more flow time/productivity improvement.

8.3.1.1.2 Potential Improvement

The flow times for the -180 and -397 GTEs are currently 133 days and 147 days respectively (in the UDOS model) with average WIP rates of 26 engines for the -180 and 53 engines for the -397 (Not including items in the parts pool). Roughly 96% of this flow time is spent waiting - in back shops, in the GTE repair areas, or in the parts pool. In the portion of the flow between the parts pool and final sell, however, only 50% of the average flow time (15 days) is spent waiting. This significantly improved ratio of productive to non-productive time is a product of the JIT flow found in this portion of the process, and is used as the basis for MDMSCs estimates of potential improvement. As shown in Table 8.3.1.1.2-1, the implementation of a JIT flow would reduce the cost of the WIP inventory by approximately 52% or $20 million (using current MM item manager data).

This change would free the approximately 11,000 square feet of floor space currently occupied in the parts pool, and eliminate the bulk of the disassembled GTE subassemblies stacked throughout the process. While no current inventory figures were provided to MDMSC, data provided by the subassembly item managers indicates that there are at least 6,538 critical parts (for the two GTEs studied) "in-work" (location and condition unknown) with a total value of at least $9 million. According to those same item managers, there are currently 203 -397 GTEs and 323 -180 GTEs in-work in the depot, out of 408 - 397s and 374 -180s on Kelly AFB. At current costs, this reoresents a WIP balance of $39 million. The actual location of many of these parts and engines within the production process is unknown, however, MDMSC suspects that the bulk of them are stored in the parts pool or are resident at one of the back shops.

GTE WIP COST COMPARISON, AS-IS VERSUS JIT
TABLE 8.3.1.1.2-1

		CURRENT SYSTEM			JIT SYSTEM			
	COST OF GTE	AVERAGE FLOW TIME	CURRENT WIP	COST OF WIP	AVERAGE FLOW TIME	AVERAGE WIP (ANNUAL)	COST OF WIP	SAVINGS UNDER JIT
-180	$76,000	133 days	203 engines	$15,428,000	69 days	106 engines	$8,056,000	$7,372,000
-397	$73,123	147 days	323 engines	$23,618,729	76 days	168 engines	$12,284,664	$11,334,065

20956

8.3.1.1.3 Risk Assessment

MDMSC projects minimal risk in the implementation of this focus study. The massive reductions in inventory levels/costs realized under JIT conditions have been extremely well-documented by numerous American, Japanese, and European corporations. As no capital investment is required, the loss incurred should this projected cost reduction not be realized is zero.

The risk that the additional inspections called out in this focus study will not reduce the final assembly reject rates is also considered minimal. This type of post-repair inspection is currently in use at the Corpus Christi Army Depot (CCAD) turbine engine facility, where they report near-zero reject rates at final assembly.

8.3.1.1.4 Duration and Level of Effort

MDMSC estimates three months will be needed to begin the process described in this focus study and 24 - 30 months will be needed to empty the parts pool and achieve a JIT process flow. This will change in response to shifting workload levels.

No further MDMSC effort is required to implement this process. Should SA-ALC personnel desire additional assistance, MDMSC will provide quotes for the additional effort requested, as required.

8.3.1.2 Establish an SPC Program for the GTE Process

This paragraph describes MDMSC's recommendations for improving the quality of the GTE process using statistical process control. The recommended data collection/ charting process is designed to allow GTE production and engineering personnel to determine the causes of rework/rejections in their process and eliminate them.

8.3.1.2.1 Rationale Leading to Change

As described in Paragraph 8.1.2.1, there is currently no process control within the GTE process. As a result, there is a high reject/rework rate found at final assembly, final test and in the field after the overhauled GTEs are delivered.

With a process as complex as that of GTE repair at SA-ALC, the only way it can be controlled is statistically. Large amounts of in-process data must be collected and compared, across time, to reject/rework rates at various points. If the correct data is

collected, the process can be reliably controlled and the reject/rework rates be reduced substantially at each point. As Dr. Deming points out, improving process quality means reduced process costs.

A statistical process control program will require a great deal of data to be collected on the GTE repair process. MDMSC recommends that the in-process data be collected at the inspection points identified on Figure 8.3.1.1-2 in the previous focus study. THIS FOCUS STUDY WILL ONLY BE EFFECTIVE IF IMPLEMENTED WITH THE REORGANIZED PROCESS FLOW DESCRIBED IN PARAGRAPH 8.3.1.1. Currently, parts are not re-inspected after repair, thus, no statistical data is available to control the repair process.

Although this statistical data is collected at several points in the process flow, the physical location of the bulk of the in-process data is the GTE inspection areas in Building 329 (MATPSI). Dimensional tolerance data and NDI defect/reject data are captured as in-process statistics before and after the repair processes. Spin balance characteristics, tolerance build-up data, and reject rates/causes are captured at final assembly, and test cell results are captured at final test. This provides multiple points at which the process can be monitored and controlled. Field failure rates should be monitored as well. MDMSC estimates that recording and charting the in-process data will add three manhours to assembly and increase the duration of MATPSI inspections by 10%. The actual statistical analysis should be performed by engineering or planning personnel and should require approximately one person half time.

MDMSC recommends the SPC program be implemented as follows:

- The dimensions/tolerance in Table 8.3.1.2-1 be recorded (for the critical parts identified) and charted using a Pre-Control Stoplight chart (PCS). This will give the SA-ALC process engineers some idea of which back shops/processes/parts contribute the largest source of process variation. Note: The characteristics on Table 8.3.1.2-1 are those MDMSC engineers suspect are significant contributors to the quality of finished GTEs. SA-ALC engineers should add any additional characteristics they suspect of significance as well. The PCS chart is extremely simple and easy to use/maintain, and thus, can be used liberally without great expense.

RECOMMENDED INITIAL QUALITY CHARACTERISTICS FOR SPC CHARTS

TABLE 8.3.1.2-1

-180

PART	CRITICAL DIMENSION	TOLERANCE (INCHES)
2nd Stage Diffuses Hsg.	DIA A	5.537 to 5.539
	DIA A	Concentric to DIA K .001 TIR
1st Stage Compressor Inlet	DIA A	2.5117 to 2.5125
	DIA A	Concentric to CL .001 TIR
2nd Stage Compressor Hsg.	DIA C	2.5202 to 2.5210
	DIA C	Concentric to DIA B .002 TIR
2nd Stage Compressor Diffuser	DIM E	.830 to .851
	DIM E	Parallel to Surface D .003 TIR
Bearing Housing Assy.	DIA F	2.0347 to 2.0353
	DIA F	Perpendicular to Surface A .0005 TIR
Turbine Wheel and Shaft	DIA C	1.1809 to 1.1811
	DIA C	Concentric to F-G .0003 TIR
1st Stage Compressor Diffuser	DIM B	.340 Maximum
Turbine Torus	DIA D	12.330 to 12.360
Combustion Chamber Liner	DIA F	4.822 to 4.842

-397

PART	CRITICAL DIMENSION	TOLERANCE (INCHES)
Turbine Nozzle	DIM A	.125 Maximum
Compressor Inlet Assy.	DIM CP	2.305 to 2.315
	DIM CP	Perpendicular to CL .003 TIR
2nd Stage Diffuser Hsg.	DIM EB	3.981 to 3.991
	DIM EB	Perpendicular to CL .004 TIR
2nd Stage Diffuser	DIA T	6.659 to 6.661
Accessory Drive Hsg. Assy.	DIA C	4.000 to 4.010
	DIA C	Concentric to CL .002 TIR
Turbine Bearing Hsg.	DIA C	2.0469 to 2.0472
	DIA C	Concentric to CL .0002 TIR

20989

- After 3 months of PCS tracking, the part characteristic distributions should be ranked in order of variance. Those parts whose characteristic(s) make up 80% of the total variance should be selected for more detailed tracking.
- Those high-variance parts selected should be tracked using Moving Average/Moving Range charts (MA/MR). One set of charts should be maintained for initial inspections and another for post-repair inspections. Both sets should be updated weekly, and the results provided to Engineering/Planning and Production Management in the RCCs involved in the repair of the part(s). Brainstorming sessions should be conducted to identify possible sources of process variability. These sources should be adjusted and the effects on process variability studied, using the MA/MR charts. Any process change which reduces variability (increases quality) should be retained. Any which does not should be abandoned.
- In parallel with the MA/MR charting, individual data points on dimensional characteristics, tolerance build-ups and balancing data should be collected by subassembly serial number and GTE serial number. These points should be plotted against the output readings for the respective GTEs at final test. This will produce charts which describe the sensitivity of a test parameter (i.e., vibration in mils, or output horsepower) to in-process quality characteristics. After six months of this, those quality and output characteristics which show high coefficients of correlation/determination should be investigated further by SA-ALC engineers. Those which show low/no correlation should be dropped from the charts. Note: Only the bottom 20% of the characteristics should be dropped from the charts. They should be replaced by newly-selected characteristics which then compete with the currently charted values. The idea is to identify those in-process factors which control 80% of the reject/rework rates, both in-process and at final test.
- Final test data should be compared to field failure rates for each GTE. Individual test data points should be charted against operating meter readings on returned GTEs. Any incidence of correlation should be investigated by SA-ALC engineers. Note: While this data may take years to appear, it can be examined historically. The logs maintained in disassembly show field operating hours by serial number and the test cell data is maintained historically by serial number. As the serial number is only removed after disassembly and replaced before final test, the two data bases can be correlated.

- At NDI, both the number of defective parts found, as well as the number of defects per part should be tracked, both for induction and post-repair inspections. This data should be tracked using a Group NP chart and a short run Group C chart respectively. This data should be handled, and used in the same fashion as the PCS and MA/MR charted data on dimensional tolerances.

The rationale behind the selection of these charts, as well as details of their construction and use, and sample blank charts, are provided in Section 8.3.1.2 of the DDB. This program was developed with the aid of an MDMSC-developed proprietary software tool. A copy of this software (An IBM-compatible Expert System) has been provided to SA-ALC engineers for evaluation.

8.3.1.2.2 Potential Improvement

The goal of this program is to identify and eliminate 80% of the sources of all rejects/rework. The current average rate at final test is 24% for both GTEs studied. If the cost of a reject is estimated at 50% of a full repair, the cost of this reject rate (at current workloads) per year is

-180

$76,000 (Repair cost) x 50% x 73 inductions x 24%	=	$665,760
-397		
73,123 (Repair cost) x 50% x 134 inductions x 24%	=	$1,175,818
TOTAL	=	$1,841,578

A reduction of 80% of this rate would be worth $1,841,518 x 80% = $1,473,262. This does not include the cost of in-process rework, as this figure is assumed to be included in the repair cost.

The annual cost of this program is estimated as:

Assembly

•3 hours at Assembly x $ 15.80/hour x 207 GTEs = $9,729

Inspection

- -180: 10% increase x 26.24 hours x $ 15.80/hour x 73 GTEs =$3027
- -397: 10% increase x 14.21 hours x $15.80/hour x 134 GTEs=$3009

Total =$6036

Engineering/Planning

- 1000 hours/year x $15.80/hour = $15,800

GRAND TOTAL = $21,836 annually

No capital equipment is required. Existing PC resources/software are judged sufficient for this effort.

Given an estimated three years from implementation to results, an MDMSC Cost Benefit Analysis (CBA) of this recommendation showed an annual savings of $1,473,262 and a five year Net Profit Value (NPV) of $3,727,875. This CBA was performed in accordance with AFR 173-15. The details are included in Section 8.3.1.2 of the DDB.

8.3.1.2.3 Risk Assessment

The risks associated with this recommendation are minor. The results of SPC programs have been demonstrated throughout industry and the techniques have been used widely since the 1950s. No capital investment is required and the recurring investment is in the form of in-house labor hours (as are the bulk of the savings).

Given the scope of the reject/rework found in the GTE process, as well as its tenacity (the problem has existed at least since 1987 - the limits of current history data), MDMSC feels the greatest risk is not implement process control. With a field life span less than half of that of a new engine, and a repair cost at or near half the cost of a new engine, these GTEs are rapidly becoming uneconomical to repair at SA-ALC.

8.3.1.2.4 Duration and Level of Effort

MDMSC estimates that one year will be required to implement this program and that three years will be required to show significant results (although results will build gradually across that period). No further MDMSC effort is required to support this program.

Should SA-ALC personnel desire additional assistance, MDMSC provide a quote on the cost of the requested effort, as required.

8.3.2 Quick Fixes

This paragraph summarizes MDMSC's Quick Fix recommendations. These are recommendations which can be implemented in less than six months, with a capital investment of $200,000 or less. Details of these suggestions, including cost analysis, can be found in the Task Order No. 15 Quick Fix Plan.

MDMSC's Quick Fix recommendations are summarized as follows:

Establish a Machine Cell of GTE Critical-Path Parts

MDMSC's analysis of the -180 and -397 GTE flows identified certain subassemblies as lying on the critical path for each engine. Any reduction in the flow time for these parts means a reduction in the flow time for the entire GTE. The bulk of the flow time for these parts are spent in the machine shop in Building 303. MDMSC recommends that several pieces of equipment currently located in Building 303 be transferred to the GTE area, as a machining cell. This will produce significant reductions in GTE flow time, and WIP inventory levels. MDMSC estimates the value of this inventory reduction at $2,145,288.

Establish a Virtual Machine Cell for GTE Critical-Path Parts

Any reduction in the flow time for GTE critical-path parts means a reduction in the flow time of the entire GTE. As part of the effort of shortening these flow times, MDMSC has recommended the use of machining cells. While these cells will significantly shorten the flow time for GTEs, they do require additional study and capital investment. Until such changes are made, MDMSC recommends the establishment of a "virtual" cell, where no equipment is moved but the scheduling of parts flows are modified to

produce some of the benefits at a dedicated in-house process cell. MDMSC estimates the value of this suggestion to be one half that of establishing the actual cell or $1,072,644.

Limit Inductions of GTEs to Delivery Requirements

In Paragraph 8.3.1.1 MDMSC has recommended an involved procedure for reducing Flow times and WIP inventory levels through the establishment of a JIT flow in the GTE process. Some of these results can be realized much more easily by simply limiting the number of GTE inductions each month to number scheduled to sell that month. This will not reduce WIP levels, but it will stop their growth. The manhours currently being spent to disassemble and inspect the over inductions can be saved. MDMSC estimates the manhour savings to be worth $93,299 each year.

Color Code Parts After Inspection in Building 329

After being inspected in Building 329, GTE parts are stacked on a conveyor awaiting routing to the parts pool or a back shop. Material handlers must remove the WCD from its plastic envelop to read the part's destination. MDMSC recommends the use of color-coded WCDs to facilitate this process. The estimated manhour savings is worth $3,543 each year.

8.3.3 Other Observations

This paragraph contains recommendations which MDMSC believes would be real process improvements but cannot be adequately quantified for inclusion as a Quick Fix or Focus Study.

8.3.3.1 Radio Tracking of GTE Parts

At SA-ALC engineering request, MDMSC evaluated the use of radio-tracking tags on GTE parts. The tags identified were manufactured by Identronix, Inc., and are designed to travel with a part through its process. Antennas can be installed at various process points to detect the presence (and identity) of a radio tag. This data is then passed to a central computer, which tracks and reports the location of all tagged parts.

Identronix, Inc., formerly of Santa Cruz, California, is no longer in business in that area (at least under that name) and MDMSC has been unable to determine if the firm still exists at all. A competitor - the Allen-Bradley Company, sold similar systems as late as

1984, but did not respond to MDMSC's request for product information and pricing. As a result, MDMSC is unable to identify a manufacturer for the equipment, nor estimate its price.

MDMSC does not recommend this system for use in the GTE area. Given the large number of parts, and highly variable flows, an enormous number of tags and antenna scanner units would be required. The automated scheduling system described in Paragraph 8.1.3 would serve GTE production needs for more effectively and economically then the radio tracking system.

This system would be extremely useful in study situations however, as a tool for Engineering rather than Scheduling or Production. The parts tagging/tracking effort described in Paragraph 8.2.1 required roughly 400 MDMSC manhours to begin, and will require another 600 - 800 SA-ALC hours to complete. The cost of this effort (at current burden MDMSC and unburdened SA-ALC rates) will be over $35,000. A radio tracking system could have reduced this cost by as much as 75%, saving SA-ALC over $26,000 in this study alone.

If SA-ALC engineers intend to continue this type of study work, MDMSC recommends they consider the purchase of radio-tracking hardware. One suite of hardware could be used to support engineering studies across SA-ALC, or even across AFLC.

8.3.3.2 Experimental Design to Investigate GTE Vibration Failures
Currently, vibration problems make up an average of 50% of the total average 24% rejection rate for the 397 and 180 GTEs. Of these vibration rejects, 76% are from excessive vibration in the turbine and compressor assemblies (rotating bodies). MDMSC concludes from this, that out-of-balance rotating parts are the single largest source of rejects/rework in the GTE repair process.

While Air Force engineers have studied the problem for several years, no systematic data appears to have been collected, and the problem appears to have continued (or even gotten worse) over the last four years. During MDMSC's investigation of this situation, SA-ALC engineers reported that they felt they had solved the problem. They concluded that, by striking the assembled rotating assembly with a rubber mallet, prior to spin-balancing, the cement used to secure the rotating parts is relaxed. The old

process, (without the use of the mallet) balanced the assemblies with the cement (a loctite substitute) in a stressed state. Subsequent handling during final GTE assembly caused the cement to relax and the assembled units to become unbalanced. The proof of this success was cited as the drop in reject rates from 35% in September 1990, to 8% in October 1990.

MDMSC does agree that this process change may be a source of improvement in the spin-balance process. MDMSC does not, however, agree that the problem has been "solved". An examination of reject rates over the last 12 months shows that this would not be the first time the rejection rate has been at (or below) 8%. The extreme variability of the rejection rates indicate that this is an extraordinarily complex problem, with many possible sources of variation. MDMSC doubts that any one factor can be said to cause the problem.

MDMSC questions the current spin-balancing process. The spin-balancing machines in use perform two-plane balancing at 1800 RPM. At this rotational speed, they are not sensitive enough to detect out-of-balance conditions to ISO standards. While MDMSC engineers have been informed that the machine's manufacturer claims they can be used effectively at virtually any rotational speed, no data supporting this claim has been provided, pending approval from the manufacturers.

The only way to learn what is causing the out-of-balance vibration is to conduct a series of scientific experiments, and document the results. MDMSC engineers recommended such a series of experiments at the beginning of Task Order No. 15, but SA-ALC engineers felt that the GTE production schedule would not support the disruption. MDMSC still feels that these experiments are critical and recommends that SA-ALC engineers conduct the Taguchi-based experimental procedure described here.

The L_8 orthogonal array shown in Table 8.3.3.2-1 contains MDMSC's recommended list of control factors. These factors were selected because MDMSC engineers feel that they are likely significant contributors to the balancing process and because they are under the control of MATPGB balancing and assembly workers. The factors are described as follows:

on the vibration of an assembled engine. These factors are primarily dimensional characteristics of the subassemblies and are listed in Section 8.3.3.2-1 of the DDB.

The L_8 array should be repeated four to six times, with the quality characteristic as the total vibration (measured in mils) experienced at final test. The standard Taguchi main-effects analysis and analysis of variance will describe the contribution of each factor (including interactions) to the control of the vibration at final test.

By graphing the quality characteristic at each run against the values of the various noise factors, a picture of the sensitivity of the GTE vibration characteristic to various noise factors can be developed. It will be easy to see which are important and which trivial. By performing a S/N ratio calculation, SA-ALC engineers will be able to evaluate the effects of changes in controls on sensitivity to noise.

APPENDIX A

LIST OF ACRONYMS AND ABBREVIATIONS

LIST OF ACRONYMS AND ABBREVIATIONS

ATP	ACCEPTANCE TEST PROCEDURE
BOM	BILL OF MATERIALS
CBA	COST BENEFIT ANALYSIS
CCAD	CORPUS CHRISTIE ARMY DEPOT
CO_2	CARBON DIOXIDE
CSR	CONTRACT SUMMARY REPORT
DDB	DATABASE DOCUMENTATION BOOK
FPI	FLUORESCENT PENETRANT INSPECTION
GTE	GAS TURBINE ENGINE
IBIS	INTEGRATED BLADE INSPECTION SYSTEM
IPI	INDUSTRIAL PROCESS IMPROVEMENT
JIC	JUST IN CASE
JIT	JUST IN TIME
MA/MR	MOVING AVERAGE/MOVING RANGE
MDMSC	MCDONNELL DOUGLAS MISSILE SYSTEMS COMPANY
MPI	MAGNETIC PARTICLE INSPECTION
NDI	NON-DESTRUCTIVE INSPECTION
NPV	NET PROFIT VALUE
OCM	ON-CONDITION MAINTENANCE
PCS	PRE-CONTROL STOPLIGHT
QF	QUICK FIX
RCC	RESOURCE CONTROL CENTER
S/N	SIGNAL TO NOISE
SA-ALC	SAN ANTONIO AIR LOGISTICS CENTER
SOW	STATEMENT OF WORK
SPC	STATISTICAL PROCESS FLOW
UDOS	UNIVERSAL DEPOT OVERHAUL SIMULATOR
WCD	WORK CONTROL DOCUMENT
WIP	WORK IN PROCESS

INDUSTRIAL PROCESS IMPROVEMENT ENGINEERING SERVICES PROCESS CHARACTERIZATION TASK ORDER NO. 15

VOLUME V
SA-ALC

QUICK FIX PLAN
14 DECEMBER 1990

CONTRACT NO. F33600-88-D-0567
CDRL SEQUENCE NO. 15A010

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8.0 SAN ANTONIO AIR LOGISTICS CENTER (SA-ALC)

As a result of the process characterization of the -180 and -397 GTEs at the SA-ALC, MDMSC has developed process improvement recommendations which are presented as quick fix opportunities. They are summarized in Table 8.0-1. This plan describes each quick fix in detail and shows the calculation of cost savings and inventory reduction values.

SA-ALC QUICK FIX RECOMMENDATION SUMMARY (TASK ORDER NO. 15)
TABLE 8.0-1

MDMSC RECOMMENDATION	IMPACT	BUDGET SAVINGS	COST AVOIDANCE			INVESTMENT COST
			FLOW TIME REDUCTION	WIP INVENTORY REDUCTION	FLOOR SPACE REDUCTION	
DESIGN OF A MACHINE CELL FOR GTE CRITICAL PARTS	THE MACHINE CELL WOULD REDUCE FLOW TIME BY ELIMINATING DELAYS IN THE MACHINE SHOP.		52 DAYS	$2,145,288	0 SQ. FT.	$25,000
LIMIT GTE INDUCTIONS TO DELIVERY RATES	THIS WOULD HALT THE GROWTH OF WIP INVENTORY A FREE MANPOWER IN DISASSEMBLY AND INSPECTION.	$93,299	0 DAYS	HALT CURRENT GROWTH (20% ANNUALLY)	0 SQ. FT.	$0
COLOR CODE WCDs BY DESTINATION	THIS WOULD REDUCE PART HANDLING TIME AFTER INSPECTION	$3,543	0 DAYS	$0	0 SQ. FT.	$0
TOTALS		$96,842	52 DAYS	$2,145,288	0 SQ. FT.	$25,000

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8.1 DESIGN OF A MACHINE CELL FOR GTE CRITICAL-PATH PARTS

The flow times of GTE parts through the repair back shops is enormous, in comparison to the actual process times required to repair them. This situation causes extremely long (four to five months) flow times for GTEs, consisting largely (96%) of non-value added delay time. The worst case of this situation is found in the machine shop located in Building 303.

To alleviate this problem, MDMSC recommends the establishment of a machining cell in the GTE area, using assets drawn from Building 303. In accordance with Paragraph 3.2.1 of the Task Order No. 15 SOW, MDMSC engineers have analyzed the relevant workload and developed such a cell. This cell was designed using an IBM-compatible software tool (simulator) known as XCELL. The results of this simulated design have been demonstrated to GTE engineers and production management. A copy of the cellular design files and a copy of the XCELL software itself, have been given to SA-ALC engineering. The results of this simulation have been confirmed by a corresponding simulation using UDOS 2.0.

This cell is designed to repair three items identified as critical-path items in the GTE repair process, and requires the transfer of three lathes, one drill press, one grinder, and a radial drill from Building 303. It also requires one welding booth from MATPNN. Two machinists and one welder are required to operate this cell (first shift only). Figures 8.1-1 through 8.1-3 show the flow of each of the parts through the cell. The cellular flow includes the use of the current in-house FPI facilities, chrome plating, painting, and heat treat remain in their current back shops.

Table 8.1-1 shows the effects on flow times of establishing this cell. As WIP reductions are proportionate to the flow time reductions (less the WIP currently in the parts pool or at back shops) MDMSC estimates the value of WIP reduction as:

-180

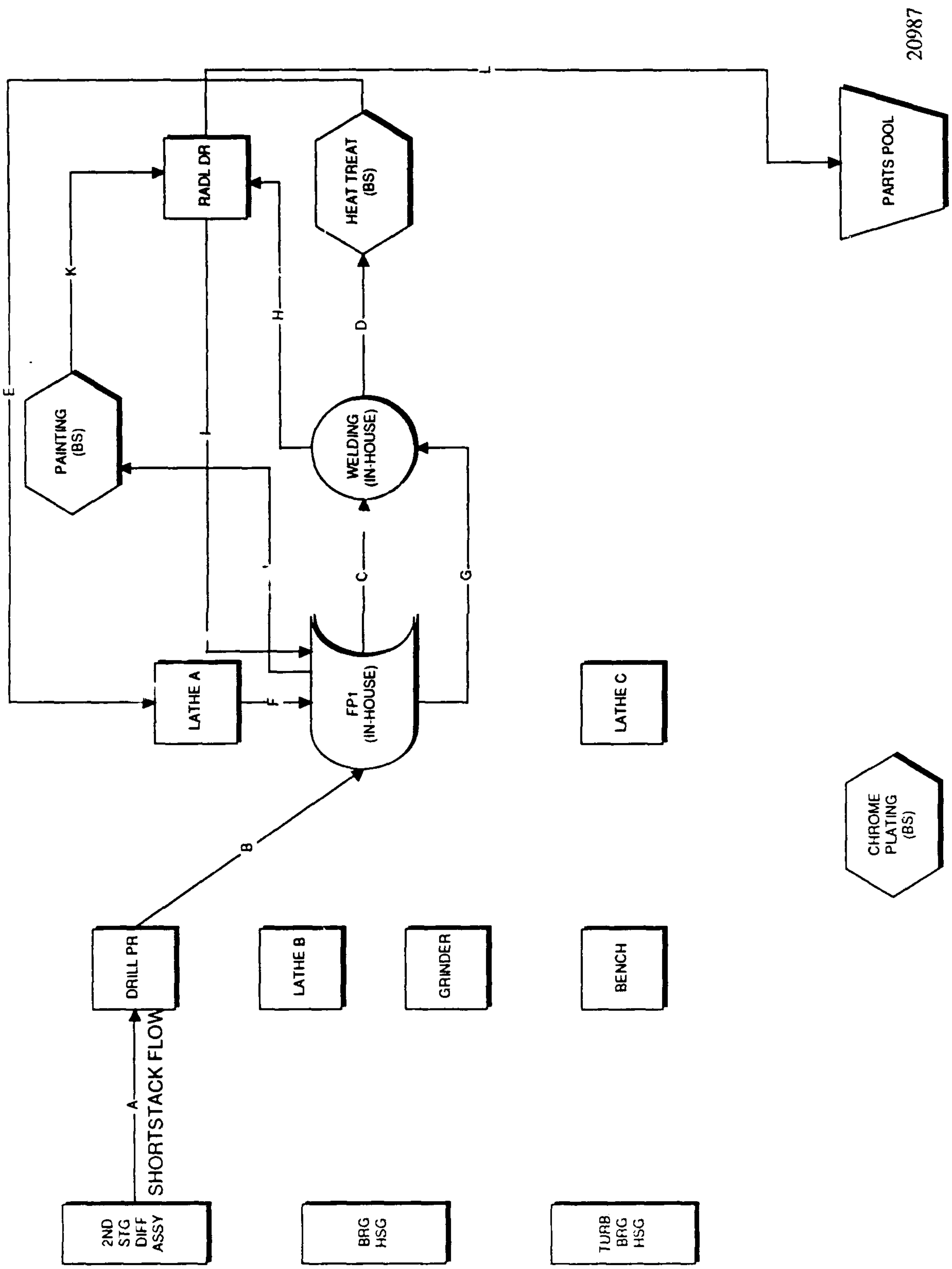
27 engines (Ave WIP) x $76,000 (Cost of Engine) x 29% reduction = $595,080

-397

53 engines (Ave WIP) x $73,123 (Cost of Engine) x 40% reduction = <u>$1,550,208</u>

TOTAL = $2,145,288

No new capital equipment or additional personnel are required by SA-ALC to implement this suggestion. MDMSC estimates the transfer and facilities cost required to establish the cell at $25,000.



SECOND STAGE DIFFUSER ASSEMBLY PROCESS FLOW THROUGH MACHINE CELL

FIGURE 8.1-1

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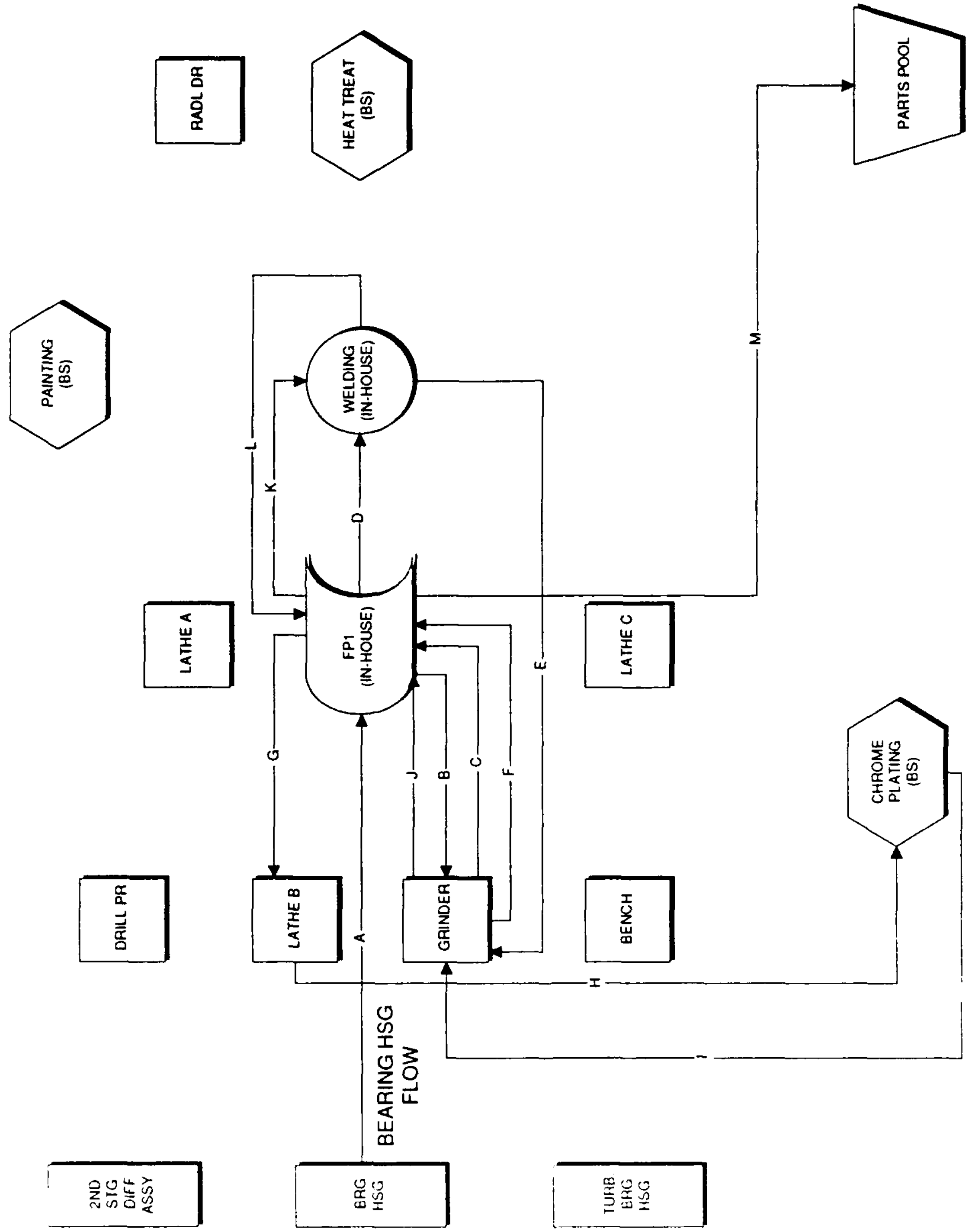
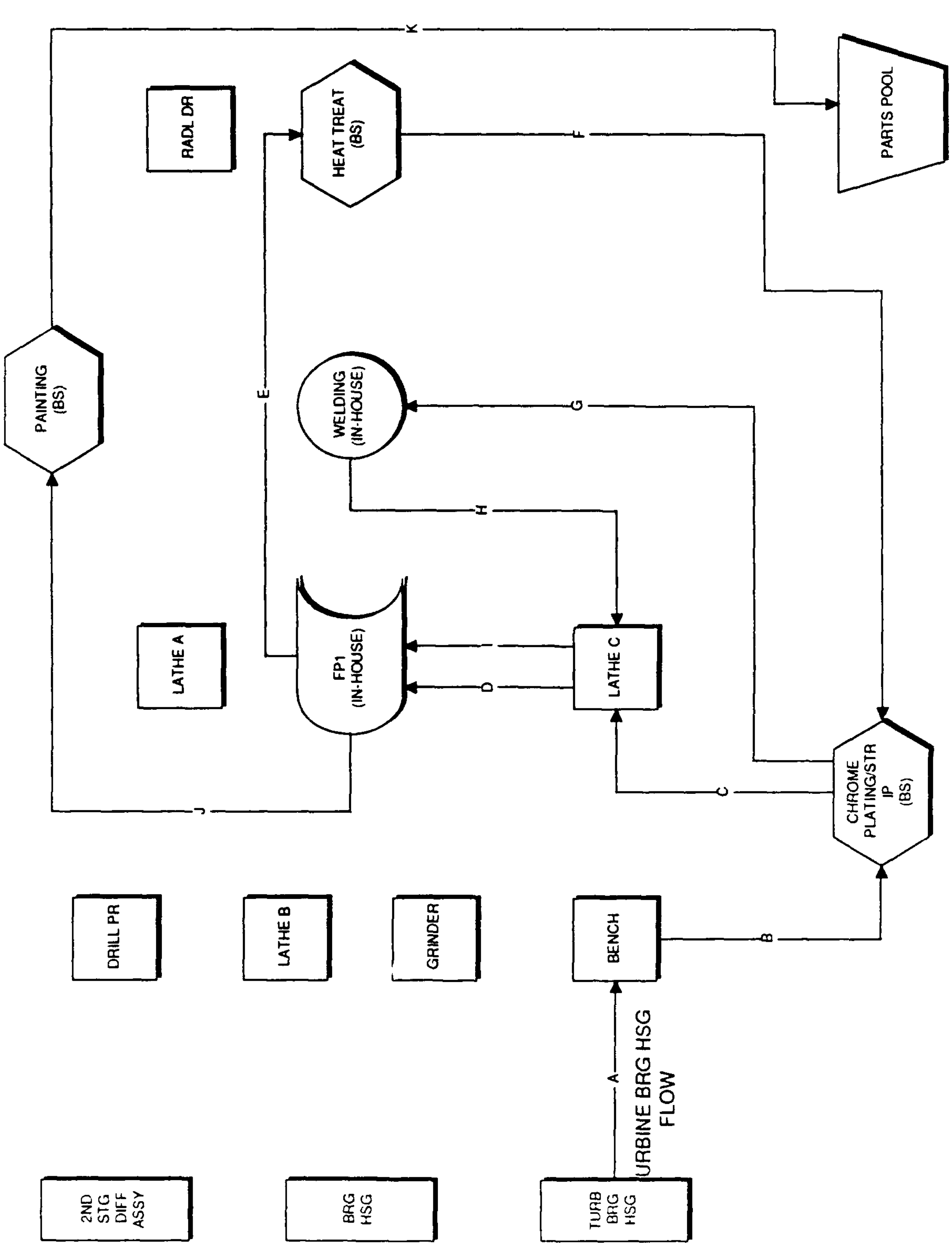


BEARING HOUSING PROCESS FLOW THROUGH MACHINE CELL

FIGURE 8.1-2



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TURBINE BEARING HOUSING PROCESS FLOW THROUGH MACHINE CELL
FIGURE 8.1-3

GTE FLOW TIME REDUCTIONS WITH MACHINE CELL
TABLE 8.1-1

	CURRENT FLOW TIME	FLOW TIME WITH MACHINE CELL	IMPROVEMENT IN FLOW TIME	% IMPROVEMENT
-180 GTE	133 days	94 days	39 days	29%
Bearing Housing	123 days	2 days	121 days	98%
-397 GTE	147 days	88 days	59 days	40%
2nd Stg Diffuser Assy	136 days	9 days	127 days	93%
Turbine Bearing Hsg	88 days	3 days	85 days	97%

Note: All values are from UDOS 2.0 simulation model.

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8.1.1 Design of a Virtual Machine Cell for GTE Critical-Path Parts

The machine cell described in Paragraph 8.1 will reduce the flow time of both GTEs significantly. It does, however, require the expenditure of capital and requires more floor space within the GTE area. In lieu of this investment, MDMSC proposes the establishment of a "virtual" machine cell.

In a virtual cell, the equipment and personnel dedicated to the cell's workload are not relocated to a single area. Rather, they remain in place, but are designated as part of a given cell. They accept only cellular workload, in spite of their location in a functional machine shop. While this system sacrifices some of the advantages of a true cell (minimal transit-times) it requires no movement of equipment and no re-allocation of floor space.

MDMSC recommends that those machines identified in Paragraph 8.1, along with two machinists, be designated a GTE machine cell and transferred to the operational control of GTE production management. These assets should not be relocated however, to avoid the costs of movement and floor space re-allocation.

MDMSC estimates the savings (in flow day/WIP inventory costs) to be half those of the actual cell. Using the savings estimated in Paragraph 8.1, MDMSC estimates the value of the inventory reduction produced by this change to be $1,072,644.

8.2 LIMIT GTE INDUCTIONS TO REDUCE WIP INVENTORIES

MDMSC has offered a focus study recommendation in Paragraph 8.3.1.1 of the CSR, to establish a JIT flow and drastically reduce flow times and WIP inventories. While MDMSC engineers recommend this focus study effort as the best way to reduce flow time and WIP, a simpler method is available, should GTE management not wish to restructure the GTE flow as described.

<u>MDMSC recommends that no more GTEs be inducted than are sold, in any month</u>. Over induction at the beginning of the process does not increase production rates or shorten flow times. With 2 - 2 1/2 years worth of WIP inventory already in the system (for the GTEs studied), adding more parts won't affect the flow at all.

Adding more parts will drive up the WIP levels and further clog/confuse the system. However limiting inductions to delivery rates will free an estimated 20% of the manhours currently consumed in the Induction/Disassembly and Inspection operations. This savings is worth approximately 5,905 manhours (using standards for inspection and disassembly) and has an annual value of:

-180:	73 GTEs x 35 hours x $15.80/hour	=	$40,369
-397:	134 GTEs x 25 hours x $15.80/hour	=	<u>$52,930</u>
	TOTAL	=	$93,299

This excess capacity could be reduced, or, could be redirected within the process. MDMSC recommends that excess personnel from disassembly be transferred to Inspection and/or final assembly, and that the Inspection area's workload be increased by re-inspecting parts returning from repair processes. This will increase production capacity (more resources at final assembly) and decrease the delays caused by rejects at final assembly.

8.3 COLOR CODE PARTS AFTER INSPECTION

Currently, parts leaving the MATPSI inspection area in Building 329 are stacked on a roller conveyor at the North East end of the building. There parts are awaiting routing to the parts pool, one of the repair back shops or to scrap. Their destination is identified on the WCD attached to the part by inspection personnel.

Expeditors must remove each of these WCDs from their plastic bag, read the destination marked on the WCD, and sort various parts by destination. The sorted parts are then batched into plastic tubs, whose destination is marked on the side, on a strip of masking tape. MDMSC estimates that this handling process requires an average of one minute per part (the WCDs must be removed and unfolded). At current workloads, the annual cost of this process for the -180 and -397 GTEs only is:

207 GTEs x 65 parts/GTE x .017 hours x $15.80/hour = <u>$3,543</u>

<u>MDMSC recommends that the inspection personnel color code the WCDs by destination.</u> Rather than print WCDs on white paper, they should be printed on several colors, which will be used for each destination. As the plastic envelops used to attach these WCDs to the parts are transparent, the expeditors will be able to determine the destination without reading the WCD. This will cost nothing to implement and MDMSC predicts it will eliminate the need to read WCDs, thus saving $3,543 annually. The savings realized for those items inspected in MATPSI but not studied in this task order would be proportional.

APPENDIX A

LIST OF ACRONYMS AND ABBREVIATIONS

LIST OF ACRONYMS AND ABBREVIATIONS

CSR	CONTRACT SUMMARY REPORT
FPI	FLUORESCENT PENETRANT INSPECTION
GTE	GAS TURBINE ENGINE
JIT	JUST IN TIME
MDMSC	MCDONNELL DOUGLAS MISSILE SYSTEMS COMPANY
SA-ALC	SAN ANTONIO AIR LOGISTICS CENTER
SOW	STATEMENT OF WORK
UDOS	UNIVERSAL DEPOT OVERHAUL SIMULATOR
WCD	WORK CONTROL DOCUMENT
WIP	WORK IN PROCESS